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THE GERMAN GROUND STATION FOR INTERCONTINENTAL SATELLITE COMMUNICATIONS

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Ernst Dietrich

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A Government-owned and -operated ground station for radio, television, facsimile, and multichannel telephone transmission over the communications satellites Telstar and Relay, as part of a NASA program, is described. The station works with a broadband and a narrow-band installation, the latter being a mobile unit manufactured by International Telephone and Telegraph Corporation. The basic principles of both systems are described, with special emphasis on the 25-m Cassegrain antenna with parabolic horn feed, unique in design. Layout, technical data, monitoring equipment, and design features are tabulated, plotted, and shown in photographs.

Author

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I. INTRODUCTION

On 22 June 1961, an agreement was signed between NASA* and the German Federal Post Office Department (DBP), giving the German Post Office the possibility to participate in experimental NASA projects for communication transmission by means of artificial satellites. The main experiments in question were those with the Telstar and Relay communications satellites (comsats), of which two each have been successfully launched in the meantime and have frequently given an opportunity to the general public on both sides of the Atlantic to appreciate the transmission quality of this novel communications means, on the screens of television receivers.

The experimental program of NASA, in addition to television, covers mainly a number of experiments for telephone transmission. In this respect, the problems of simultaneous transmission of several hundred telephone calls and the multiple contact with one and the same satellite by a relatively large number of ground stations were to be investigated. In addition, experiments with sound transmission, telegraphy, telemetering, and facsimile transmission are on the program.

In order to participate in these extensive experiments, it became necessary for the DBP to erect a ground station satisfying the multiple require- /266
ments of the various experimental series and meeting future demands of practical operation in later commercial utilization of satellite systems.

Since the Federal Republic Germany has had no practical experience in the planning of ground stations and since stations of similar type that could have been used as prototype were not yet completed in other countries, entirely new methods frequently had to be used in the planning of the ambitious project. It should be mentioned specifically at this point that the ATT (American Telephone and Telegraph Co.) which had erected the ground station Andover (Bibl.1) in the state of Maine for its studies, made available all its plans and was always willing to assist with ideas and practical data. In addition, several European administrations were soon cooperating closely in this novel field of communications technique, permitting an exchange of practical experience and technical data, as well as inspection of completed installations in the various countries.

In Europe, France was the first to erect such a ground station in Pleumeur-Bodou (Bibl.2), followed by England in Goonhilly (Bibl.3, 4); these stations were completed in time to start transmission experiments immediately after launching of the first active communications satellite Telstar I, on 10 July 1962. Some time later, Italy joined the experiments with a station erected in Fucino. In the meantime, Spain has built its own ground station and the Northern countries Denmark, Norway, and Sweden cooperated in constructing a common installation on the Island Raö on the west coast of Sweden. This particular station is only equipped for reception but can also be used for experiments in radio astronomy.

* National Aeronautics and Space Administration, USA.

Finally, we should mention that Japan and Brazil have erected ground stations and that Canada is building a station which presumably will be in operation by end of 1965.

II. PLANNING PRINCIPLES

Of decisive importance for planning a ground station are the characteristics of the satellites over which the communication is to take place. In order to participate in the NASA experiments, it will be necessary to adapt the German ground station to the Telstar and Relay satellites with respect to frequency range, radio-frequency bandwidth, type of polarization of the RF radiation, and beacon frequency for antenna tracking. In addition, it is necessary to know the reception power on the ground and the transmission power from ground to satellite, in order to obtain the desired transmission quality in the various experiments.

The height of the orbit of the satellite above the surface of the /267
earth is of importance for planning the ground station since this determines the orbital velocity of the satellite from which the required rotational speed for the tracking equipment of the antenna can be calculated. In addition, the orbit can be used for computing the maximum and minimum distance between satellite and ground station, which is of importance for determining the corresponding radio field damping. The most important system data of the Telstar and Relay satellites, so far as they enter the planning of the ground station, are compiled in Table 1.

TABLE 1

CHARACTERISTICS OF THE EXPERIMENTAL SATELLITES TELSTAR AND RELAY

		Telstar	Relay
Reception frequency	Mc	6,390	1,725
Transmitting frequency	Mc	4,170	4,170
Beacon frequency	Mc	4,080	4,080
Bandwidth of the transponder	Mc	50	23
Antenna gain, transmitting and receiving end	db	0	0
Receiver sensitivity	db	13	13
Transmitter power			
in one-way transmission	w	2	10
in two-way transmission	w	0.7	3
Maximum distance	km	12,500	9,000
Polarization		circular	circular

If the characteristics of future satellites should differ greatly from those of Telstar and Relay, changes in the ground stations may become necessary which had not been anticipated in the planning; this is especially so

since the technique of this novel means of transmission is still too much in the development stage.

Since it is impossible to obtain exclusive frequencies for satellite systems within the suitable frequency bands of 1 and 10 Bc*, certain frequency bands must be used in common with other services. As found during the Space Communications Conference in Geneva (1963), the frequency bands predominantly in question for satellite communications are those already allotted to stationary radio services, i.e., to directional radio in these specific frequency ranges, by the Frequency Allotment of Atlantic City (1947). However, common use of frequency bands presupposes an extremely careful coordination of the two services since it is mandatory to keep interference by satellite radio service with the transmission by existing directional radio lines to an absolute minimum.

In a country such as the Federal Republic of Germany with its widely /268 branched directional radio network, it is especially difficult to keep mutual interference within tolerable limits. For reasons of coordination, suitable sites for ground stations are only such terrains that are far enough removed from the main channels of the directional radio networks. Consequently, the problems arising in a common use of certain frequency bands are of considerable importance in planning a ground station.

During the Space Radio Conference in Geneva (1963), the frequency bands around 2 Bc were excluded from the use for satellites. Therefore, the reception frequency of the satellite Relay (1725 Mc) will no longer be used in the new systems.

Since it is planned to have the German ground station also make broadband transmission experiments, such as long-distance telephone operation on several hundred channels and, in television, on bandwidths of several megacycles, it will be necessary to erect a system with very high antenna gain and low-noise receivers.

At a maximum distance of 12,500 km, which is in question for the satellite Telstar in accordance with Table 1, a basic transmission damping (between spherical radiators) of 187 db is obtained for 4170 Mc. If an antenna of about 58 db gain is used on the ground, which corresponds to a parabolic mirror of about 25 m diameter at a frequency of 4 Bc, a signal power of -96 dbm** is obtained at the receiver input of the ground station in one-way transmission experiments over Telstar (2 w) in the direction from the satellite to the earth. Since frequency modulation has to be used in the transmission for increasing the signal-to-noise ratio, it will be necessary that the signal arriving at the receiver is above the noise threshold which, in frequency modulation,

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* GHz = giacycle = 1000 megacycles = billion cycle = Bc. Also, gigacycle or Gc.

** dbm is used as abbreviation for decibel (db) when the common zero level is one milliwatt in 600 ohms, i.e., power in decibels measured for a reference level of one milliwatt.

usually is about 12 db above the noise level, i.e., the signal power must be at least 16 times higher than the noise power. If, for the entire reception system, a resultant noise temperature of for example $T = 60^{\circ}K$ is assumed, a value that can be reached only in combination with a maser* cooled by liquid helium, and if a value of $B = 25$ mc is assumed for the radio-frequency (RF) bandwidth, then the noise power will be

$$10 \cdot \log k \cdot T \cdot B = 10 \cdot \log 1.38 \cdot 10^{-23} \cdot 60 \cdot 25 \cdot 10^{6} \cdot 10^{3} = -107 \text{ dbm}.$$

Here, $k = 1.38 \times 10^{-23}$ w-sec/deg (Boltzmann constant). The noise threshold which, according to the above statements, is about 12 db higher will thus be near -95 dbm.

Thus, the above-defined signal power of -96 dbm is already by 1 db lower. Therefore, in this case the receiver must be provided with a frequency negative feedback (Bibl.5) so as to reduce the critical value, a method described already in 1939 (Bibl.6) for frequency modulation but very seldom used until now because there was no requirement for it. In broadband transmission with /269 this method, a reduction in the noise figure by about 4 db can be reached in operation.

For narrow-band transmission with, for example, 2 Mc RF bandwidth, the noise power of the receiver is considerably lower than in broadband transmission. Therefore, in narrow-band transmission a lower antenna gain will be sufficient and a higher value can be admitted for the resultant noise temperature of the receiver, so that a parametric amplifier can be advantageously used at the input, requiring much less expenditure than a maser. Here again, special measures must frequently be used for reducing the noise figure.

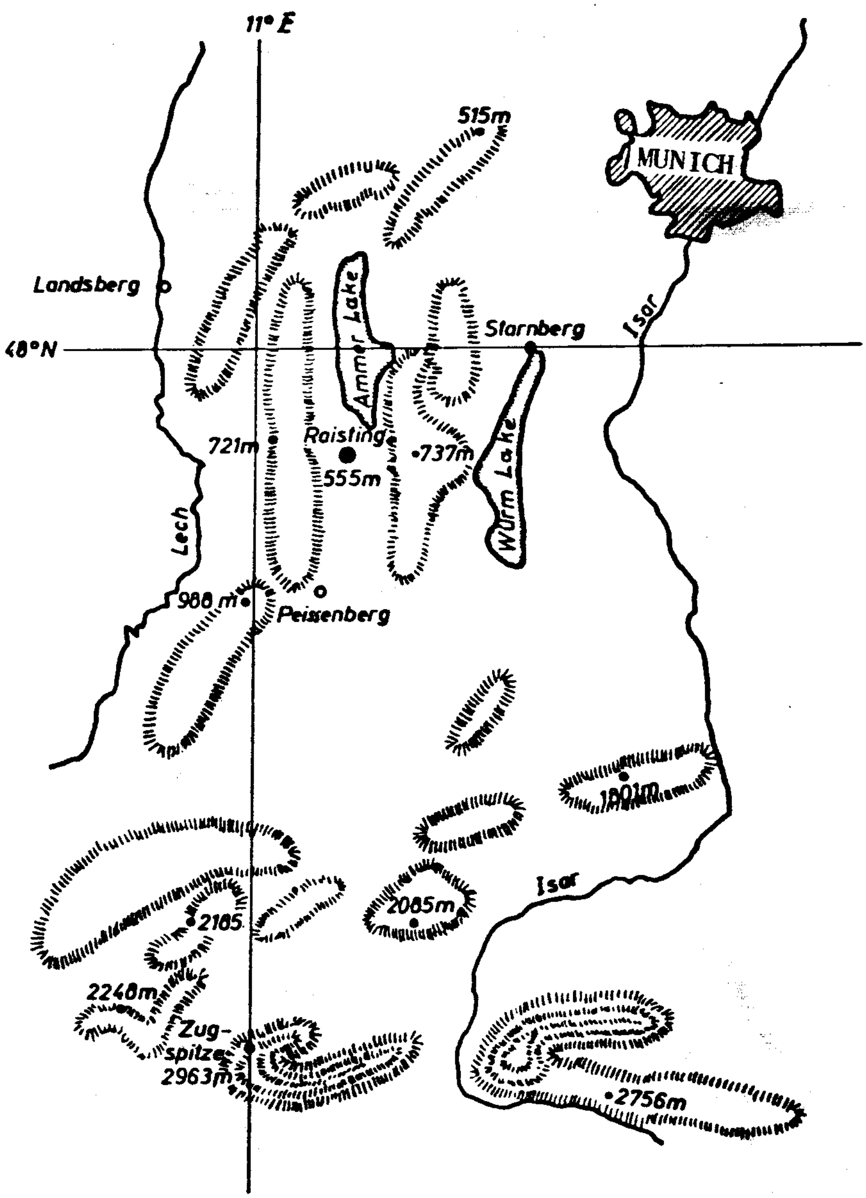
For the direction from the earth to the satellite, noise is not quite as critical since a sufficiently strong transmitter with about 2 - 10 kw power can be used on the ground without much difficulty.

Despite the very high level difference between transmitter output and receiver input, it is possible to use a common antenna for both transmission and reception in the ground station, since the high requirements made on the necessary simplexing switch are fully met today. This saves considerable expenditure of money and greatly simplifies operation of the station in comparison to a system with separate transmitting and receiving antenna.

Similarly, the beacon frequency for automatic antenna tracking is received by the same antenna. Consequently, if the satellite rise point is calculated in advance, the antenna can be aligned to the predetermined point at the necessary time. As soon as the beacon frequency from the satellite is beamed into the reception system of the ground station, the strongly focusing or highly directive antenna, swivable in all directions, will automatically track the moving satellite with extreme accuracy. Since this method, on failure of the highly complex automatic system, may lead to protracted dropout of the system, a tracking of the antenna by a program control is usually provided in

* Microwave amplification by stimulated emission of radiation.

the ground stations. In this case, the antenna is controlled over magnetic tape fed with the orbital data of the satellite to be tracked.



To permit transmission experiments during the test period not only from the ground station itself but also from as many localities in the German Federal Republic as possible, a connection with the German telecommunication system will be necessary; this connection must be of the broadband type since also television transmissions are scheduled.

Construction of a broadband ground station is an ambitious project, so that we had to use a deadline for project completion of about three years starting from the design stage, under normal conditions. One difficulty in the Federal Republic was the fact that it is quite difficult at present, with zero unemployment in the country, to find a sufficient number of skilled technicians for such a large and novel project. In addition, the terrain layout, acquisition of the necessary building lots, and procurement of the building permit for such an unconventional installation consumed quite some time. In /270 addition, extensive geological investigations were necessary to determine whether the subsurface was suitable for erecting the ground station.

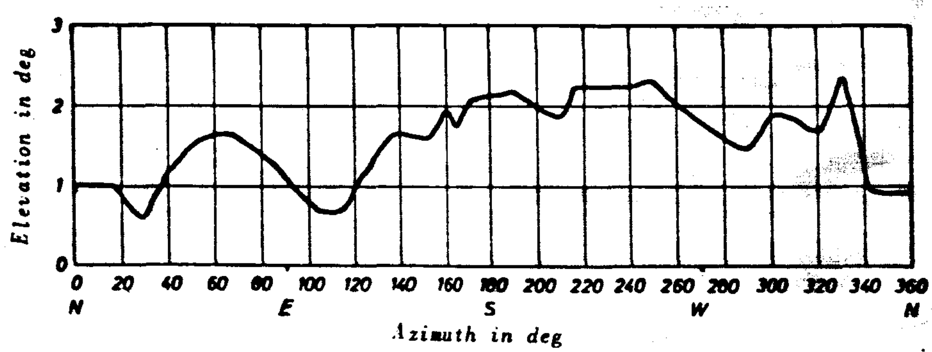


Fig.2 Horizon of Raisting

In order to participate actively in the NASA experiments at the earliest possible date despite these delays and, specifically, to gain sufficient experience in the operation of the highly complex electronic devices in such a /271
ground station, the DBP decided to erect a mobile narrow-band system (Bibl.7) in addition to the broadband system, which was procured completely assembled directly from the ITT* Federal Laboratories in Nutley, New Jersey (USA).

The most important system characteristics of the narrow-band and the broadband installation of the German ground station are compiled in Table 2. In the broadband system, the 2-Bc transmitter was omitted since no satellites with 2-Bc reception frequency will be launched in the future. Thus, broadband experiments, i.e., also occasional television transmissions over the Relay satellite, can be made only on the receiver end in the German ground station. Transmissions over Telstar, conversely, are possible in both directions.

III. SELECTION OF SITE

Extensive investigations showed that, for erection of a ground station in the Federal Republic, the terrain of the so-called "Raisting Basin" would be most suitable. The following viewpoints were decisive for selecting the vicinity of Raisting:

1. The station must be located in a plain surrounded by mountains so that

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* International Telephone and Telegraph Corporation.

TABLE 2

SYSTEM CHARACTERISTICS OF THE NARROW-BAND AND BROADBAND INSTALLATION OF THE GERMAN GROUND STATION

	Narrow-Band Installation	Broadband Installation
1. Antenna array		
Cassegrain antenna	9 m diameter	25 m diameter
Aperture angle	140°	180°
Distance of the parabolic reflector	3 m	6.5 m
Antenna weight and 3-db value for circular polarization		
at 4170 Mc	48 db, 0.6°	58 db, 0.20°
at 6390 Mc	51 db, 0.39°	61 db, 0.13°
at 1725 Mc	41 db, 1.4°	–
Radome	–	49 m diameter 39 m height
Azimuth motion	$\pm 300^{\circ}$	$\pm 380^{\circ}$
Elevation motion	-2° to $+92^{\circ}$	-1° to $+115^{\circ}$
Antenna control	Manual setting and automatic tracking	Magnetic-tape control and automatic tracking
Type of drive gear	Hydraulic drive	Hydraulic drive
Setting accuracy	0.02°	0.003°
2. Transmitter		
Frequency	1725 Mc 6390 Mc	– 6390 Mc
Output stage	Water-cooled klystron; 10 kw	Water-cooled traveling-wave tube; 2 kw
Bandwidth	2 Mc	25 Mc
3. Receiver		
Frequency	4170 Mc	4170 Mc
Noise temperature of the input amplifier	Uncooled parametric amplifier, 290°K	Maser cooled with liquid helium, 4.5°K
Equivalent noise temperature of the total reception system at 7.5° elevation (4170 Mc)	350°K	about 50°K
4. Base band	12 – 60 kc	20 cps to 5 Mc
Peak stroke	0.6 Mc	10 Mc

(cont'd.)

	Narrow-Band Installation	Broadband Installation
5. <u>Current supply</u>	Mains: 180 kv-amp	Mains: 80 kv-amp Batteries: 2 × 2304 amp-hr/10 hrs Diesel units: 2 × 155 kv-amp 1 × 23 kv-amp

extraneous interference sources, specifically from the immediate vicinity, can be shielded off. As shown in Fig.1, this condition is ideally met by the selected terrain. Figure 2 shows the optical horizon, seen from Raisting. The graph shows that there are shielding mountain ranges almost over the entire circle, up to an elevation of 1° to 2°. The surrounding hills, conversely, must not be too high so that the moving satellites can be tracked as long as possible. In Raisting, operation up to an elevation of about 3° is expected.

2. The main channel of the directional radio lines between Stuttgart and Munich passes north of Raisting at a distance of about 30 km. However, Relay and Telstar, moving on orbits with a slight inclination toward the Equator, never appear north of Raisting. Therefore, the antenna of the /272
ground station will be directed only toward the southern portion of the hemisphere when operating over these experimental satellites, so that mutual interference with the directional radio channel presumably will not occur. In addition, it was found that no antennas of any directional radio station are aligned with Raisting, over a circumference of several hundred kilometers. Therefore, the terrain is not covered by any other directional radio line operating on the same frequencies.

For calculating the possible mutual interference between directional /273
radio stations and ground tracking stations, the Fourth Studies Commission of the CCIR, in its Report No.209, gave calculation methods which, according to the final decisions of the Space Radio Conference (Geneva, 1963), must be used for determining the so-called coordination distance. Using the technical data of the ground station Raisting, at 4 Bc, the possible interference between surrounding directional radio transmitters of +55 dbw* radiated power and the Raisting receiver will be at a distance of 380 km under the most unfavorable conditions and of 320 km, for the opposite direction at a frequency of 6 Bc. The countries lying within these possible interference zones are shown in Fig.3. If the main beam of a directional transmitting antenna deviates by a few degrees from the direction to the ground station, the zone within which interference is possible becomes considerably smaller. The degree to which the interference possibility, under the assumption of corresponding angular dampings, decreases between the transmitter of the ground station and the surrounding directional

* dbw = measure of power expressed in decibels below one watt.

radio receiver stations, at a frequency of 6 Bc, is also shown in Fig.3.

3. Radio interference from the immediate surroundings is not expected, since the vicinity is purely farming country.

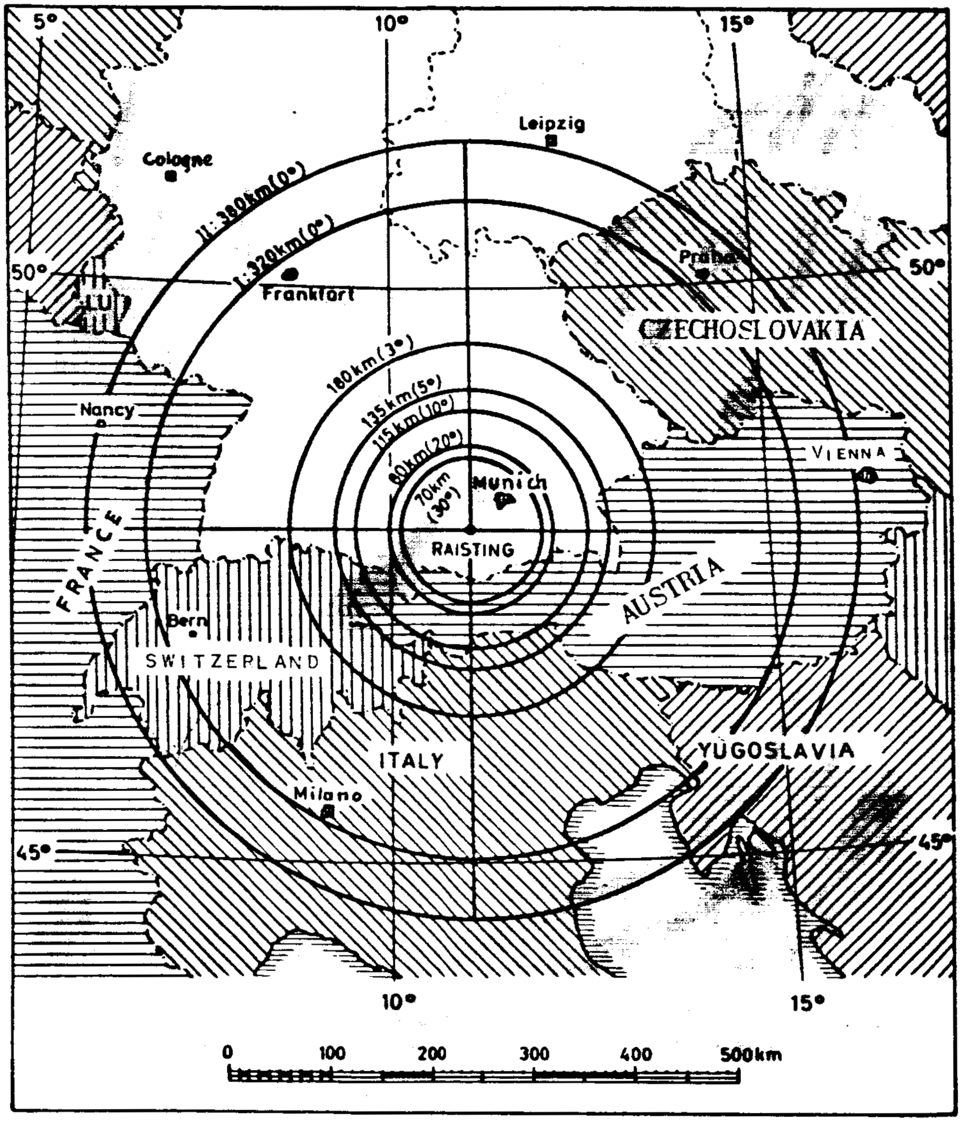

Fig.3 Coordination Distances in the Vicinity of Raisting; I at 6 Bc and II at 4 Bc and Interference Zones for 6 Bc at Various Angular Decouplings

4. The airlines shown in special maps indicate that Raisting is outside of the most densely traveled routes of commercial airliners. This point is of importance since reflections from aircraft may produce interference in the receiver systems of the ground station because of the resultant overshoot from remote directional radio transmitters.

5. The German ground station was to be located as far south as possible since, according to studies made predominantly in Great Britain, future satellite systems presumably will more frequently make use of equatorial orbits. This is specifically true for synchro satellites on equatorial orbits. In addition, it is advisable not to have ground tracking stations in Europe spaced too closely, so as to keep the transmission lines for countries without own ground stations from becoming excessively long. Therefore, it is intended to keep the distances from Pleumeur-Bodou or Goonhilly to the maximum possible.

6. Comparable antennas of broadband installations in the United States, France, and England are erected on natural rock to prevent shifting of the foundation. This means that high requirements are made as to the building base. The subsurface in Raisting does not consist of rocks but the soil conditions are rather favorable in general.

7. The terrain must offer possibilities for expansion. As far as can be judged today, the final installations of a ground station will require /274

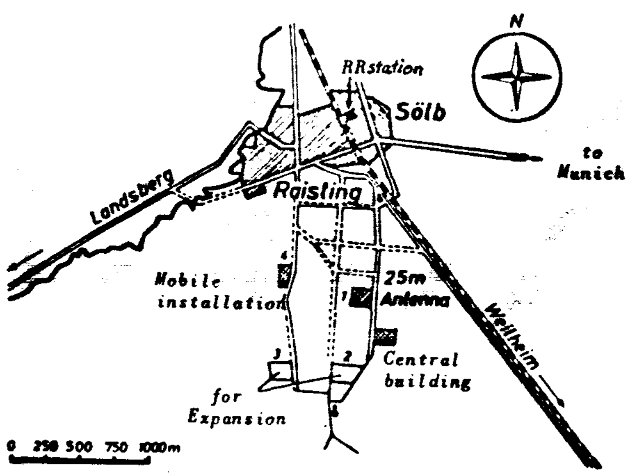

Fig.4 Position Plan of the Ground Station Raisting

at least five antenna systems and one central building, housing all technical equipment and used for centralized supplying of the entire object. To prevent mutual interference with free radiation of the antennas, they must be spaced at about 600 - 800 m, with the intervening terrain as flat as possible.

8. Raisting has favorable access roads and railroad connection; high-tension lines (20 kv) run nearby. In addition, the near and far surroundings offer advantageous living conditions for the personnel if the necessary housing /275 can be made available by new construction.

9. The surroundings of Raisting are considered earthquake-proof. No permanent deformations of the subsoil are expected.

First, the DBP purchased four separate building lots with a total of 85,000 m^2 south of Raisting (Fig.4) for the ground station. The main building was erected on the center lot. One other lot was used for erecting the narrow-band installation and another lot for the antenna of the broadband installation. The fourth lot is intended for a second large antenna array which will then become necessary in the very near future, before starting practical operations.

IV. NARROW-BAND INSTALLATION

For transport, the entire narrow-band installation can be housed in four vehicles:

1. One trailer for the antenna mount (Fig.5);
2. One trailer for the antenna dishes (Fig.6);
3. One trailer for the heat exchanger;
4. One tractor-trailer with built-in transmission equipment.

The technical equipment had been mounted on the trucks and wired as far as possible at the manufacturer's plant. This is specifically true for the extensive equipment in the closed truck with the transmitting equipment, which is air-conditioned and also has sufficient space to be used as control room. The arrangement of the instruments in this tractor trailer is shown in Fig.7. The connecting cables required between the antenna array and the transmitting equipment in the operating trailer are already cut to length and provided with the proper plugs. Consequently, the ground station can be taken in opera- /277 tion after an erection time of 2 - 3 days, if a sufficient number of properly trained assemblers is available.

The technical data of the narrow-band system are shown in Table 2. The structure of the antenna itself is clearly indicated in Fig.8.

Directly behind the antenna, in order to obtain short antenna lead-ins, the high-frequency units are installed; these rotate with the antenna on any change in direction and can be remote-controlled from the service truck.

As shown in the block diagram of the overall installation (Fig.9), the communication signals to be transmitted are fed over CF output units to a modulator. The frequency-modulated IF of 71.5 Mc is then fed to a 2 or to a 6 Bc mixer, depending on whether experiments over Relay or Telstar are scheduled. The following 10-kw power stages contain one four-cavity klystron with water cooling each. The four cavities can be tuned over remote control from a common three-phase motor which operates over four individually controllable couplings. Potentiometers, coupled with the axles, relay the respective position of the tuning to the control desk in the service room. The heat exchanger for the cooling water, as shown in Fig.8, is mounted to the base of the antenna scanner.

The communication signal with a carrier of 4170 Mc, received from the satellite (see Fig.9), is fed, across a frequency bypass which separates the

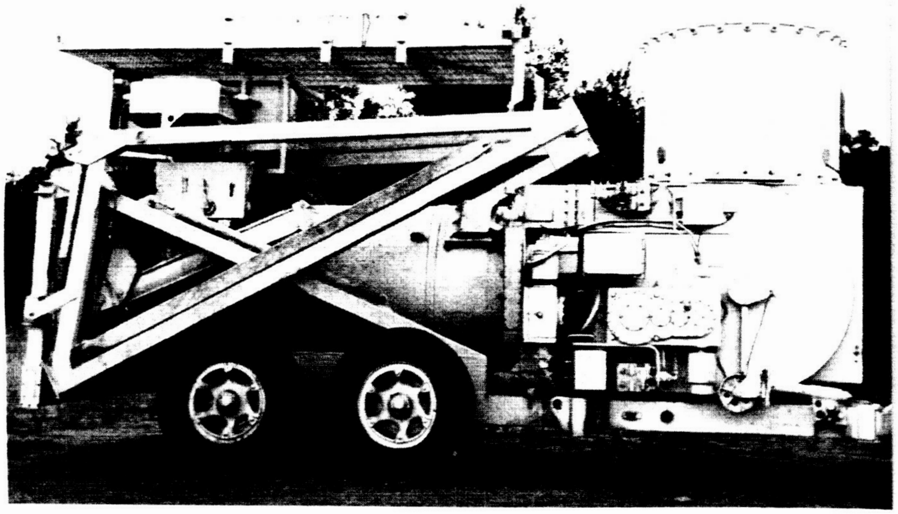

Fig.5 Trailer with Antenna Mount

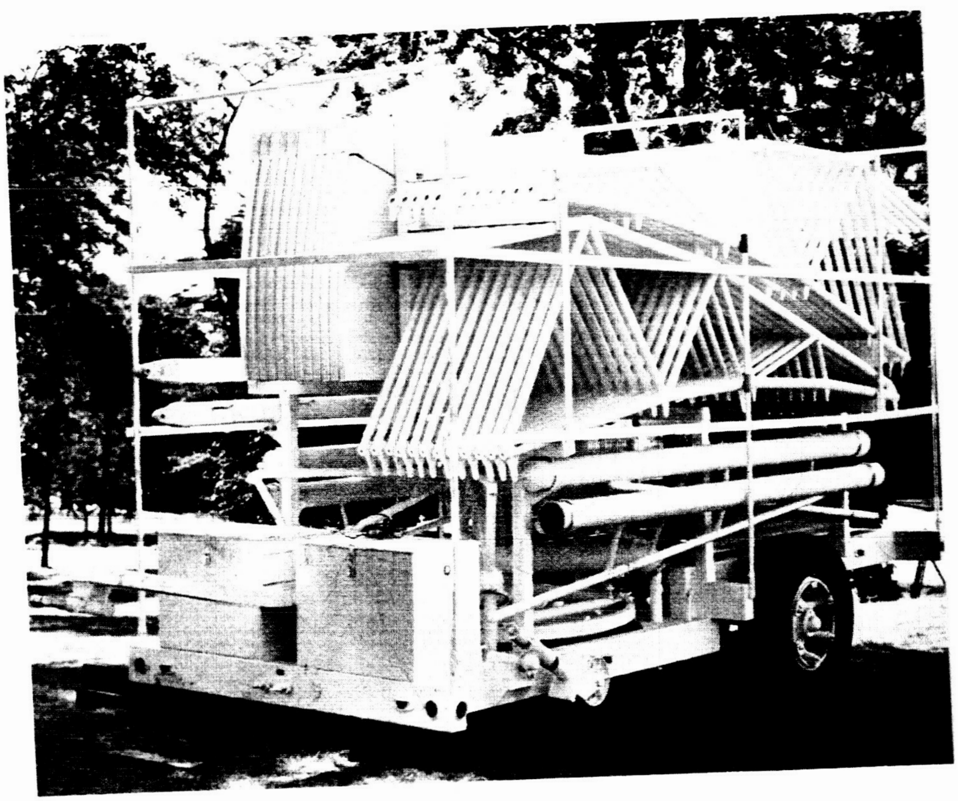

Fig.6 Trailer with Antenna Dishes

beacon frequency of 4080 Mc from the operating frequencies, to the parametric amplifier whose pulsing frequency operates with 13.92 Bc. After conversion

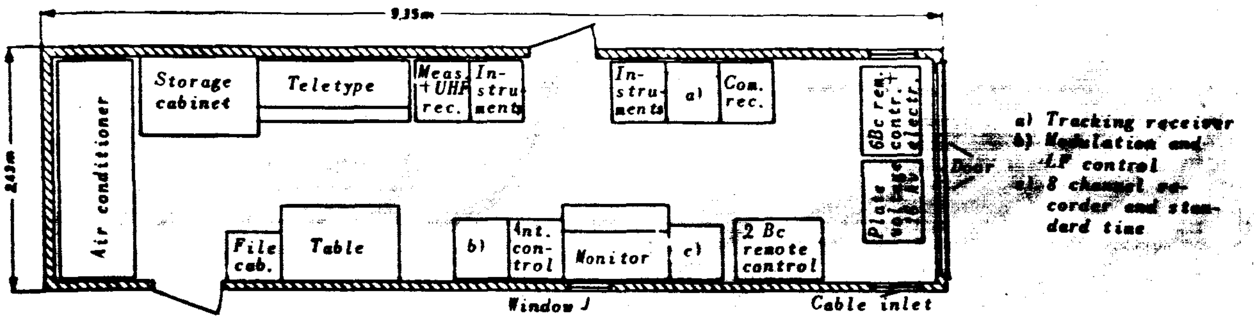

Fig.7 Instrument Layout in the Service Trailer for the Narrow-Band System

into an intermediate frequency of 65 Mc, the actual demodulation is effected in the operating room, making - in this case - use of a circuit for reducing the critical value, which is suitable only for narrow-band transmission and which also automatically compensates the Doppler shift. This circuit is known in the American literature as "phase-locked loop" (Bibl.8).

The demodulation is followed by the CF reception system.

In all, installations for 12 telephone channels of a V-120 system are /279 in existence in the narrow-band station in Raisting, suitable for experimental calls and for widely differing tests and experiments over the satellite system. For official calls, a service channel is used below the base band (12 - 60 kc) in the LF position.

The running fix on the satellite is taken by remote control of the hydraulic antenna drives from the control desk, in accordance with precalculated orbital data. On incidence of the beacon signal (4080 Mc) into the beacon receiver, the automatic antenna scanner starts operating. As shown in a highly simplified sketch in the block diagram (Fig.9), the four rod antennas acting as receiving antennas and arranged in a square, are connected with the analyzer in accordance with the monopulse method (Bibl.9) which is known from radar technique; the analyzer produces the phase separation of the sum channel and a separation of the two difference channels for azimuth and elevation. After amplification and conversion into a frequency position favorable for the final interpretation (9.8 Mc), both phase and amplitude of the beacon signal voltage at the output of the beacon receiving system are compared in the sum channel with phase and amplitude in the two difference channels. Here, the phase /280 difference will give the direction and the amplitude will give the magnitude of the antenna declination. Consequently, two error direct voltages are obtained which are proportional to the angular deviation for azimuth or elevation and which initiate control of the hydraulics for tracking of the antenna.

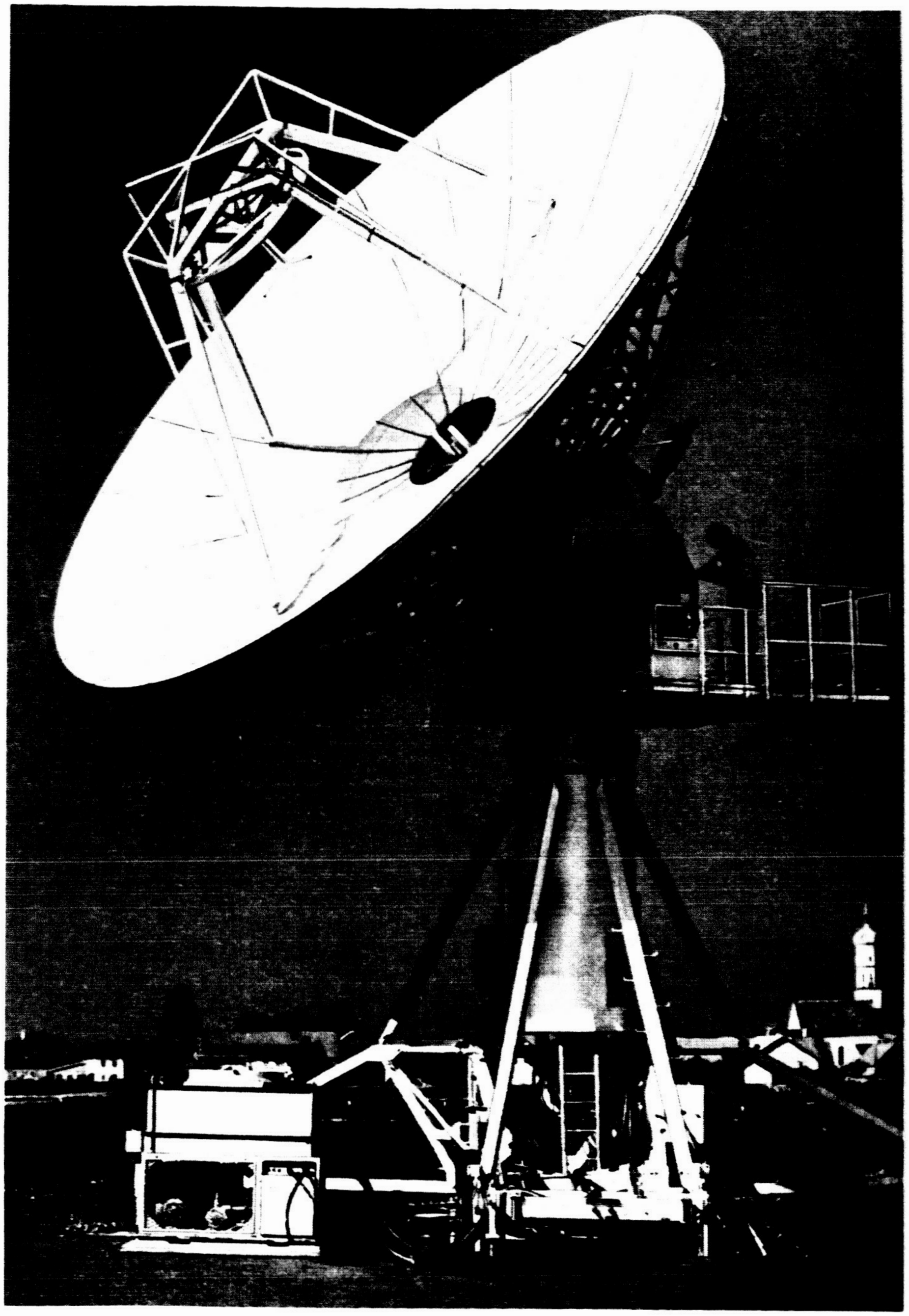

Fig.8 Antenna of the Narrow-Band System

Here again, because of the high noise component and the Doppler shift in reception of the beacon signal, the "phase-locked loop" circuit is used.

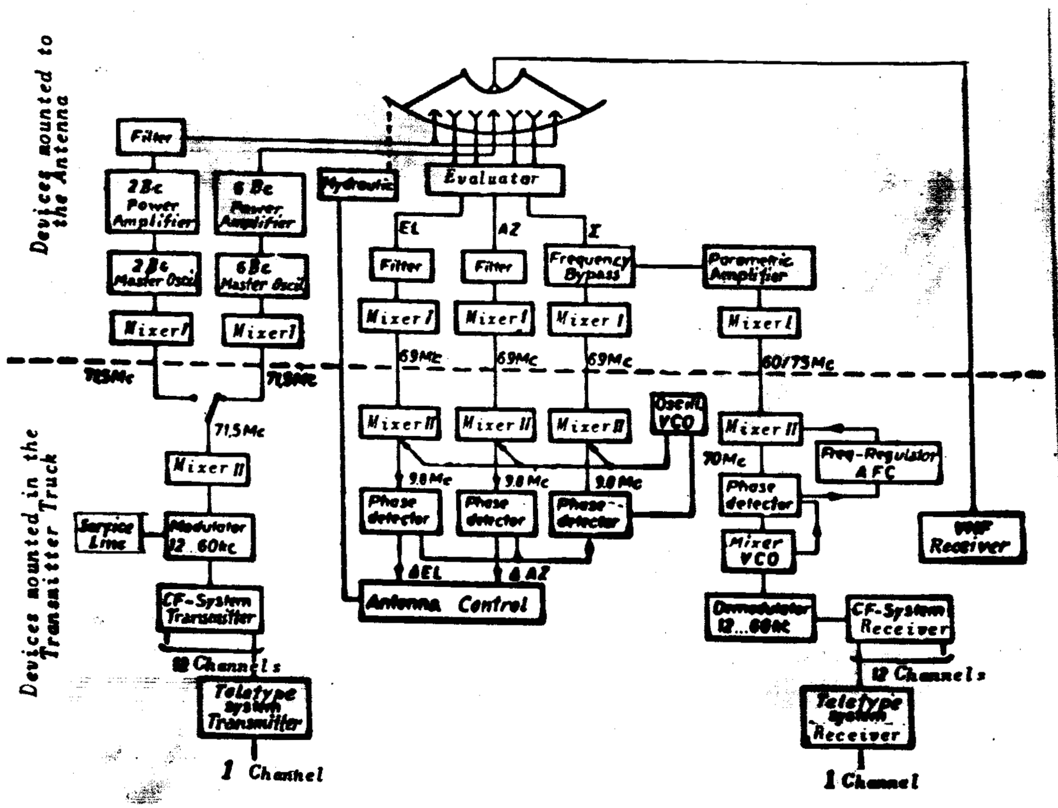

Fig.9 Block Diagram of the Narrow-Band System

V. BROADBAND INSTALLATION

1. Antenna

a) Principal Array

As mentioned in the planning principles in Section II, an antenna with a gain of about 58 db at 4 Bc is required on the receiving end of the broadband ground station. It is logical to use conventional directional antennas as prototypes, specifically those used for superrange communication which frequently show a very high antenna gain. However, since as low as possible a noise temperature is required for the antenna of a ground station of this type and since the antenna, in addition, must be rotatable in all directions, a comparison with radio telescopes is much more logical.

Nevertheless, in connection with com sats in general, new methods must be used for further reducing the noise temperature with respect to conventional antennas in radio astronomy and for obtaining an antenna with as great a band-

width as possible, which is of great importance for future satellite systems which, presumably, will operate simultaneously on several different frequency bands.

In the American station Andover and in the French station of Plemeur-Bodou, parabolic horn antennas were erected which, no doubt, have optimum broadband properties and radiation patterns. As shown in Fig.10, both upper and lower antenna space rotate in this antenna type together with the azimuthal rotary motion. In varying the elevation, only the antenna itself is rotated about its longitudinal axis because of the presence of a HF coupling installed in the throat of the horn slightly above the upper antenna space. This means

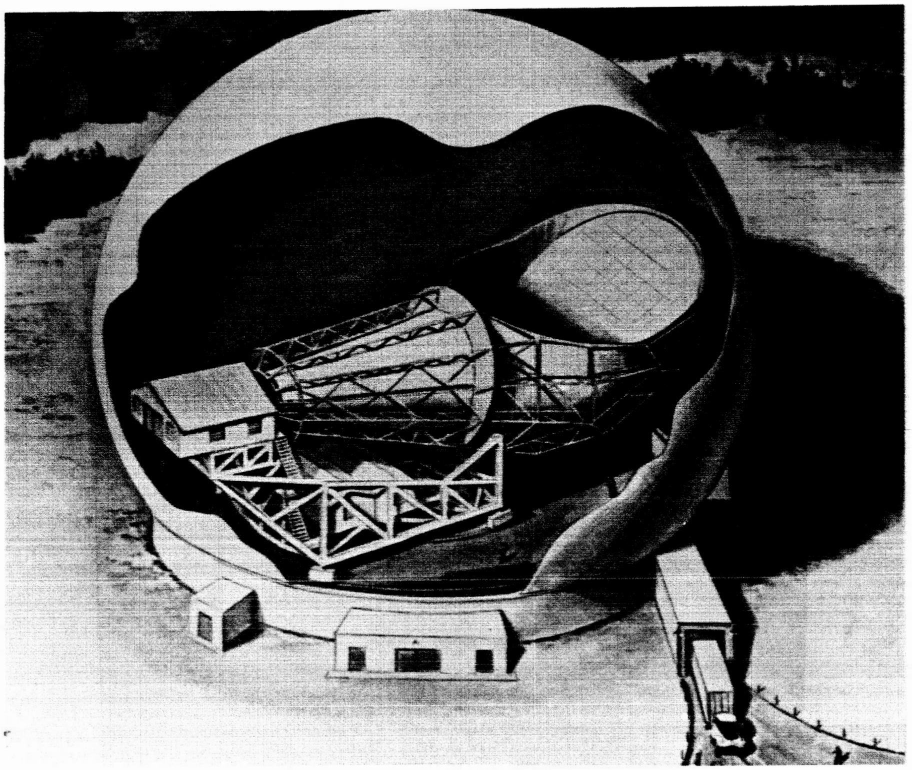

Fig.10 Model of the Parabolic Horn Antenna of Andover

that the instruments mounted in the two antenna operating rooms always remain vertical. In addition, the operating personnel can remain in the rooms during operation of the installation, when the antenna is in motion. Also, this antenna type has the advantage that the input amplifier of the receiver in the upper antenna space can be connected directly to the output of the horn, thus avoiding losses due to long lead-ins which would result in an increase of the noise temperature. With each tenth decibel damping in the lead-in, as long as a value of 0.5 db is not exceeded, the noise temperature increases by approximately 6.7°K (Bibl.5). For 1 db loss, the exact value is 59.7°K. For example, /28 if a given receiving system has a total noise temperature of 26°K, a lead-in loss of 0.1 db will result in an increase to 32.7°K. Consequently, the noise

power of the receiver increases by 1 db, since 10 log 32.7/26 = 1. This means that the lead-in loss, with respect to the noise, has a value ten times higher than would correspond to the decrease in signal power.

The length of the horizontally installed large horn parabolic reflector of Andover is about 48 m, with an aperture diameter of about 20 m. An inflatable dome - which also in German is frequently called a "radome" in accordance with the American terminology - of 49 m height and a maximum diameter of 64 m protects the entire unit from inclement weather. The weight of the movable mass is 345 tons in all.

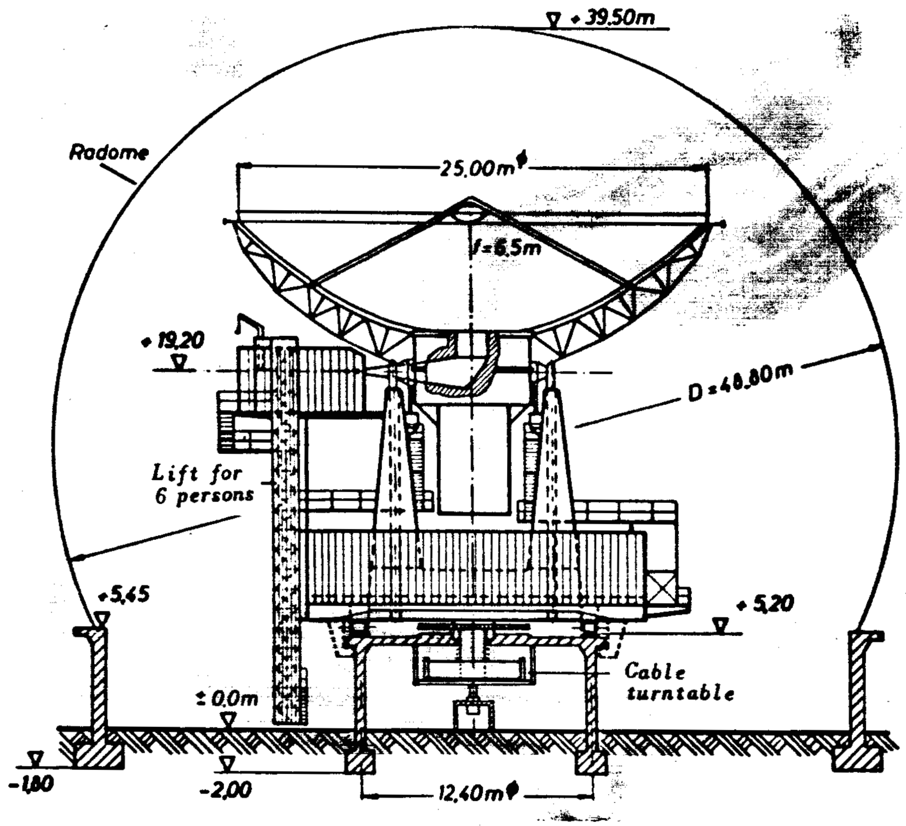

Fig.11 Principal Design of the Cassegrain Antenna with Parabolic Horn Feed

The development stage of antennas for ground stations is by no means completed. Numerous investigations are in progress to find entirely new shapes which, at lower weight and simpler overall design, would still have satisfactory transmission properties. The German Post Office Department, for this reason, has decided to escalate the development in this field, using a Cassegrain antenna with parabolic horn feed for the Raisting station; this is an antenna type not yet used in any other ground station but which, for various reasons, seems to be quite promising. In this design, a large parabolic reflector is illuminated by a relatively small parabolic horn across a collecting /282

reflector, mounted near the focus of the paraboloid on struts; the small horn is mounted directly behind the main reflector (Fig.11).

A main component of this antenna is the gantry for the reflector dish composed of 144 plates. The individual supports for the dish are combined in a hub which, for changing the elevation, is rotatably supported in two large A-frames. The two supports are mounted to a rigid base frame which is provided with a high-load central bearing for azimuth motion (Fig.12).

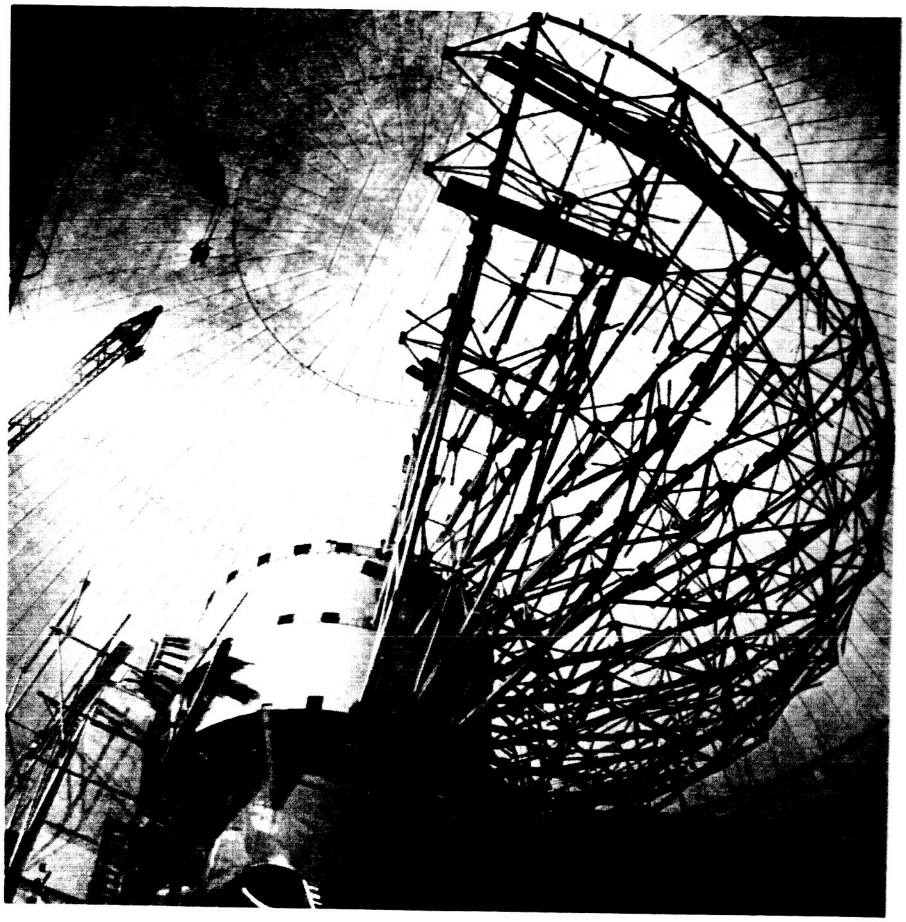

Fig.12 Design of the Reflector Support

Since the throat of the parabolic horn feeder is provided with a HF coupling, the same advantages as those obtained with a larger parabolic horn antenna is obtained for the rotational motions. Consequently, it is possible to connect the receiver directly to the exit of the throat and thus to avoid long lead-ins. In some types of radio telescopes with a large parabolic reflector, not operating on the Cassegrain principle, a low-noise preamplifier of the receiver system is installed directly behind the receiving antenna, located at the focus of the parabolic reflector. In that case, however, diffi- /283

culties in operation become unavoidable but at least there are no long lead-ins to the receiver. Such a solution, for a liquid-helium-cooled maser in an omnidirectional antenna has excessive drawbacks.

To obtain an antenna gain of about 58 db, at a reception frequency of 4170 Mc, it is necessary to fix the diameter of the parabolic reflector of the Cassegrain antenna to 25 m, since the contact efficiency in this case is only a little more than 50%. This efficiency is about 5% lower than in comparable /284 directional radio antennas since, for obtaining small secondary lobes, it is necessary to design the collecting reflector in such a manner that the areal illumination on the main reflector decreases by about 15 db toward the edge of this reflector.

The final form of the collecting reflector, determined by model experiments based on a paraboloid, has a flange along the edge which is tangent to the paraboloid. The outer diameter of this reflector is 2.30 m. The diameter of the aperture of the small parabolic feeding horn of 1.80 m is by 0.5 m smaller than the outer diameter of the collecting reflector, thus preventing radiation overshoot beyond the flange of the collecting reflector. The ratio of focal length to diameter of the main reflector was selected as 0.26, so as to obtain small secondary lobes and high reradiation damping. For reducing the 90° back scattering, a cylindrical flange of 0.5 m width was attached to the edge of the reflector.

As a special feature of the design, Fig.11 shows that the mobile masses are concentrated toward the center so that only a single concentric ring of runways of 12.40 m diameter is necessary to absorb the vertical forces. The total weight of the movable mass is 280 tons; specifically, the inertia moments are considerably lower than those of a large parabolic horn antenna, so that a higher maximum acceleration is possible at equal driving power. A comparison of the dynamic properties of three different characteristic antennas is given in Table 3. Because of the high velocity in azimuth motion, the Raisting antenna is able to track satellites of a minimum altitude of 2000 km, up to elevation angles of 86°.

b) Contour Accuracies

Because of the high frequencies, extremely high requirements must be made as to the contour accuracy in erecting the antenna since the deviations with respect to the wavelengths must be sufficiently small. Good radiation patterns can be expected only if the required accuracy of the contour of the main reflector, collecting reflector, and parabolic horn feed is strictly maintained and if these three elements are accurately aligned with respect to each other.

A great advantage of the Cassegrain antenna lies in the fact that only few molds are required in pressing the high-precision dish of the large reflector. For example, for the Raisting antenna only four different basic molds were required. The individual plates of the dish (Fig.13) are of sandwich construction with a "honeycomb core" of 38 mm thickness and two aluminum cover sheets of 0.5 mm thickness, the honeycombs being formed of aluminum foil of 0.60 mm thickness. These three elements are assembled on a solid die, which

TABLE 3

DYNAMIC PROPERTIES OF THREE CHARACTERISTIC ANTENNAS

		Andover	Raisting (25-m)	Raisting (9-m)
Weight	Az	344×10^3 kp*	280×10^3 kp	6.0×10^3 kp
	El	220×10^3 kp	120×10^3 kp	3.34×10^3 kp
Inertia moment	Az	5.7×10^6 kp·m·sec^2	1.25×10^6 kp·m·sec^2	1.5×10^3 kp·m·sec^2
	El	1.0×10^6 kp·m·sec^2	0.9×10^6 kp·m·sec^2	1.2×10^3 kp·m·sec^2
Driving power	Az	2 × 25 HP = 2 × × 24.66 PS**	2 × 25 HP = 2 × × 24.66 PS	20 HP = 19.72 PS
	El	2 × 10 HP = 2 × × 9.86 PS	2 × 10 HP = 2 × × 9.86 PS	10 HP = 9.86 PS
Gear ratio	Az	15,107:1	6572:1	1800:1
	El	18,344:1	11,418:1	3600:1
Maximum velocity	Az	1.5°/sec	3.5°/sec	10°/sec$^{1)}$
	El	1.23°/sec	2.0°/sec	5°/sec$^{1)}$
Maximum acceleration	Az	1.2°/sec^2	2.0°/sec^2	6°/sec^2
	El	3.2°/sec^2	2.0°/sec^2	3°/sec^2
Dynamic directional accuracy	Az	$\pm 0.003^\circ$	$\pm 0.003^\circ$	$\pm 0.1^\circ$
	El	$\pm 0.003^\circ$	$\pm 0.003^\circ$	$\pm 0.1^\circ$
Starting friction moment	Az	21×10^3 kp-m	6×10^3 kp-m	8.4×10^3 kp-m
	El	< azimuthal	< azimuthal	8.4×10^3 kp-m
Running friction moment (Å 0.05°/sec)	Az	14×10^3 kp-m	4×10^3 kp-m	2.7×10^3 kp-m$^{2)}$; 7×10^3 kp-m$^{3)}$
	El	< azimuthal	< azimuthal	4.2×10^3 kp-m$^{2)}$; 9.4×10^3 kp-m$^{3)}$
Minimum tracking rate	Az	< 0.01°/sec	< 0.005°/sec	0.004°/sec
	El	< 0.01°/sec	< 0.005°/sec	0.004°/sec

1) Maximum velocity limited in servocircuits 2) At a wind velocity of 40 km/hr
3) At a wind velocity of 97 km/hr

* kp = kilopond = weight of the mass unit 1000 gm at the locus of normal gravitational acceleration = 1 kg; kpm = kp-m or kg-m.

** PS = German horsepower = 0.9863 hp.

is produced with an accuracy of ±0.127 mm relative to the paraboloid; the individual plates are bonded by means of a modern hot-laminating process under /286 vacuum. The edges of the resultant sandwich sheets of 39 mm thickness were tightly sealed with a strip, using the same laminating process. This structure, using paper for the honeycomb, is also popular for gliders; it imparts exceptionally high rigidity to the individual plates at very low specific weight ($4.8\ kg/m^2$). Therefore, a manufacturing tolerance for the individual plates within the reflection area of ±0.5 mm with respect to the given paraboloid can be guaranteed. In the assembly, the plates were connected at six points with the steel framework of the reflector mount. For this purpose, six threaded bushings are inserted and cast into the honeycomb structure from the rear, without extending as far as the reflector face. In view of the differing expansion at temperature fluctuations, the four outer attachment points were provided with counterbushings and rubber buffers permitting a lateral shift by ±1.25 mm.

The individual plates were mounted in zenith position and simultaneously precalibrated by means of a precision mounting template, which is visible in Fig.13. By means of this template, rotatably mounted to the axis of the reflector, markings were etched on the reflector (after mounting) for about 900 test points, maintaining strict temperature conditions ($20^\circ C \pm 5^\circ$), so as to obtain calibration marks at accurately defined points. By means of this template, the spacings of the individual markings from the vertex were accurately defined. Therefore, the contour accuracy of the entire reflector could be checked by optical means with the aid of these 900 test points and, if necessary, corrected by a recalibration. In such recalibration, the elevation setting at the attachment points can be varied by ±12 mm. Since, because of its specific weight, a certain deformation of the large reflector as a function of the elevation is possible, the final calibration of the antenna dish was done at an elevation angle of 40°; the plates were recalibrated until the neutral marks of the test scales, starting from the vertex, appeared in a theodolite under the respective correct angle. By means of this process, the deformation of the reflector at various elevations (from 15° to 15°) could be determined even after assembly was completed. At the most unfavorable elevation, a contour accuracy of ≤ ±1 mm is specified in the inner portion of the reflector up to the supports of the collecting reflector and of ≤ ±2 mm in the outer portion. The interspaces of about 1.5 mm between the individual plates were sealed on the rear by aluminum foil which, to allow for possible temperature fluctuations, was fluted at the center.

For the contour accuracy of the collecting reflector, a value of ≤ ±0.2 mm was required and, for the parabolic horn feed, of ≤ ±0.4 mm. Final adjustment of the collecting reflector was effected across a servomechanism; aligning of this particular reflector requires extreme precision and it is well possible that a later adjustment during the final rating of the radiation pattern will become necessary.

c) Bearings and Drive Mechanism /287

As shown in Fig.11, lead-through of the horn on one side of the hub requires an elevation seating with a relatively large bore; for this reason, /288

Fig.13 Mounting of the Reflector Dish

two different roller swing bearings are used for the elevation seating.

The azimuth seating which, as mentioned above, consists of a central bearing in the base frame, absorbs only radial forces; the entire antenna array rests on four roller trolleys which rotate about the central bearing on a smoothly ground circular rail. The four conical rollers of 450 mm diameter are ground with a slight crown to prevent rim pressure. To create sufficient possibilities for the lead-through of supply lines, a large bore diameter will be required in the central bearing. The single-row cylindrical roller bearing, used at this point, has a bore diameter of 1500 mm. This means that a hole of about 1250 mm is available for the lead-through of the supply lines.

The drives for azimuth and elevation have the same design. In both cases, gear rims with a gearing of extremely high pitch accuracy with a 6-m pitch diameter are used. The azimuth gear rim, furnished in two parts, is permanently mounted to the antenna pedestal, while only one gear-rim segment is installed on both sides of the hub for elevation in view of the fact that the rotational angle during elevation remains within the limits of -1° and $+115^{\circ}$.

For the drive mechanism, hydraulic drives are used; for azimuth, two units of 25 hp each driving power and, for elevation, two units with 10 hp each are used.

Each unit is equipped with two hydraulic motors and operates, over corresponding reduction gearings, on two separate pinions that engage the large gear rims. The hydraulic circuit in each unit is so adjusted that one of the hydraulic motors drives the antenna while the other motor counteracts the antenna motion by a slight braking effect. In this manner, any play in the drives as well as between pinion and gear rim is prevented.

Each individual drive unit is provided with a mechanical solid friction brake, which can be operated across a direct-current magnet. In addition, an electric auxiliary drive can be connected with the gear mechanism over a clutch coupling, so that the antenna can be shifted even without the hydraulic mechanism in certain cases, for example in mounting or calibrating. An automatic locking mechanism prevents the simultaneous cut-in of hydraulic and auxiliary drives.

As shown in Fig.11, four safety elements are attached to the antenna base frame which, in the case of destruction of the radome, immediately engage the top portion of the base plate so as to keep the antenna stationary in case of emergency.

d) Antenna Operating Rooms, Lift and Cable Turntable

The dimensions of the placement areas for the instruments in the two antenna operating rooms can be figured out from Figs.14 and 15, where also some of the instruments themselves are indicated. The upper room has a floor area of 31 m^2 and the lower one, of 198 m^2. Both rooms are air-conditioned. To save as much weight as possible, aluminum sheeting of 1 mm thickness was used

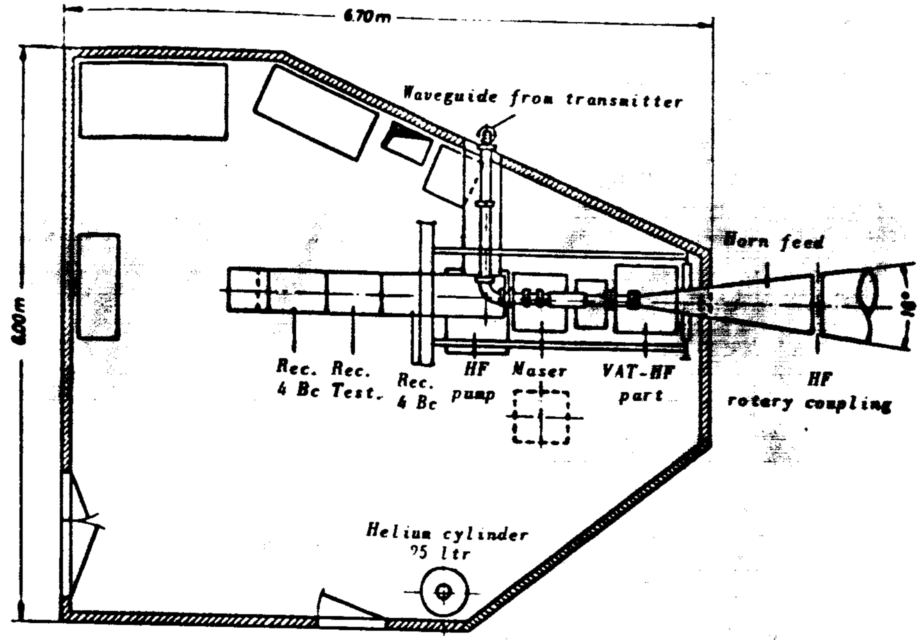

Fig.14 Upper Antenna Operating Room

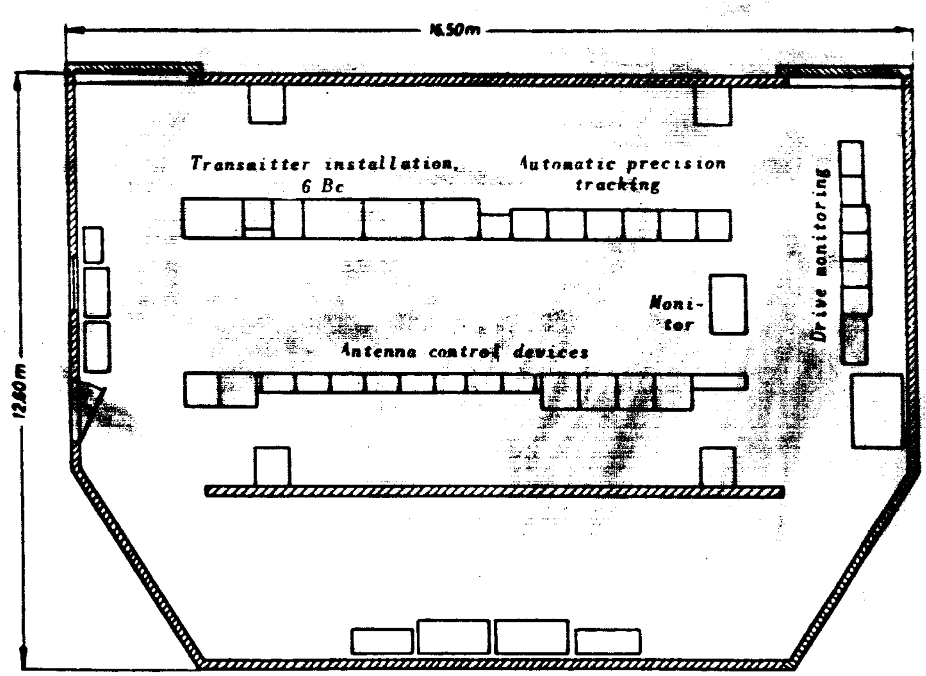

Fig.15 Lower Antenna Operating Room

for the roofs and walls on the outside, while the inside was lined with Moltoprene sheets of 30 mm thickness. The floor consists of plates laid on a support truss; the plates can be individually removed to permit access to any point, providing for lead-throughs for ventilating ducts, etc.

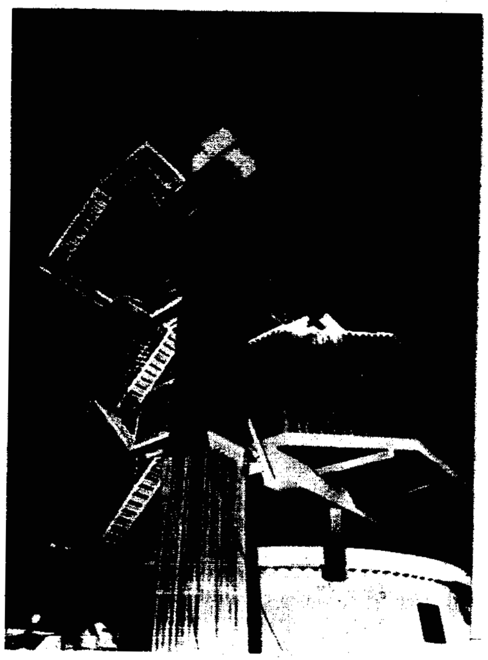

Fig.16 Elevator Shaft and Stairway

To facilitate actual operation and to save as much personnel as possible, a lift with a capacity for 450 kg cargo or six persons was installed in addition to a stairway, to give access to the antenna operating rooms (Fig.16). During azimuth tracking, the elevator shaft covers a ring-shape area of the floor. Therefore, acoustical and optical warning signals are given during the antenna motion, in order to prevent accidents.

Since electronic instruments are housed in the operating rooms that rotate together with the azimuth motion, it became necessary to provide special devices for numerous supply lines in the extension of the rotational axis, permitting as large as possible a rotary range. Therefore, a cable turntable was constructed for the telecommunications cables (Fig.17). One end of a spiral strip of about 40 m length, to which the individual cables are attached, is permanently mounted to the rotating antenna base plate over a cable cage across the azimuth bearing; the other end is connected with the stationary cable grate which leads to the next distributor. The vertical supports of the spiral strip are provided at their lower end with balls that facilitate the motion during the rotary process on the platform covered with steel plates and Resopal and having a diameter of 6 m. For dissipating the gaseous helium, leaking from the maser, a corrugated tombac pipe is attached to the spiral strip; this pipe is

sufficiently flexible to follow the rotary motions. The high-tension supply lines go across slip rings, and the intake and discharge of cooling water for the air-conditioning units is made possible by a water rotary coupling mounted to the lower end of the axis of rotation.

e) Foundation and Track Rim /291

Since the antenna, in accordance with predetermined orbital data, is to be aligned with the satellite with extreme accuracy, it is necessary that also the foundation be extremely stable. To prevent a unilateral settling of the foundation - a tolerance of 2 mm has been assumed as permissible in the calculation - , the soil below the foundation ring was pretreated over a width of 9.5 m and a depth of 9 m by depth jolters used at 120 points spaced at about 2 m. In all, 190 cubic meter gravel was thus mixed with the soil. This caused

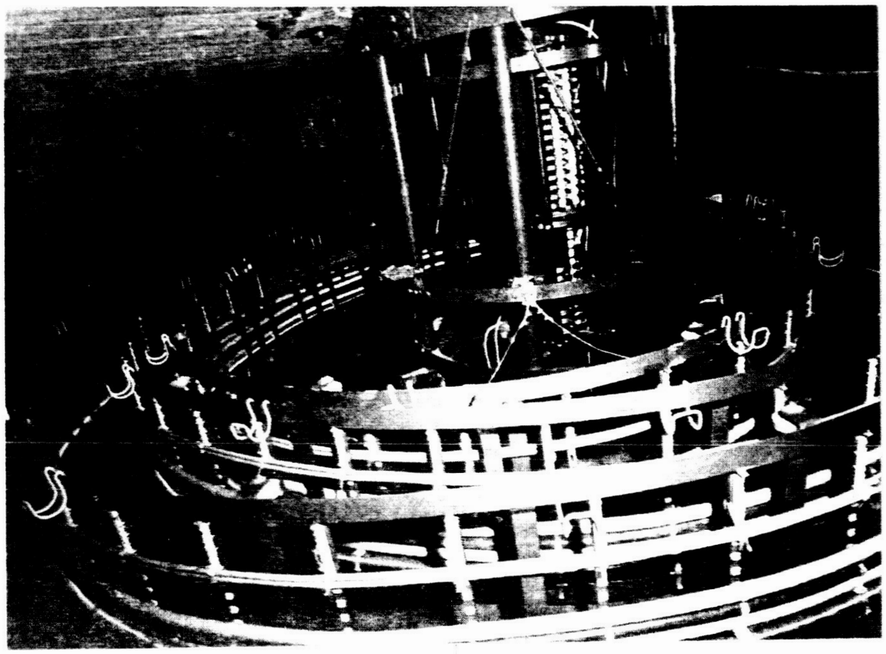

Fig.17 Cable Turntable

the treated terrain surface of 420 m^2 to settle by 12 cm. Thus, the subsoil was not only homogenized by this measure but also further compacted, so that the foundation ring despite shallow understructure and despite a total load of almost 900 tons could be kept relatively narrow. To detect any settling of the foundation, the lower end of a steel pipe of 5 cm diameter was cemented 31 m deep into the foundation along the foundation axis and was extended to the terrain surface, surrounded by a protective pipe of 12 cm diameter. It is presumed that, at this depth, no shift in the subsoil due to the load exerted by the structure takes place; this provides a reference point by means of which any settling of the foundation relative to this point can be noticed immediately by optical means. Since six reference points were marked along the circum- /292

ference of the annular foundation, even unilateral displacements could be detected.

The circular runway rail of 12.4 m diameter on the foundation pedestal had been ground smooth in the factory and was delivered in 12 sections. After assembly and mounting, this track was aligned with the center of gravity of the earth by means of a tube level. For this purpose, the inside of the rail was provided with a tubular rim, half filled with oil and provided at the top with openings of 2 cm diameter, spaced by about 1 m each, for measuring purposes.

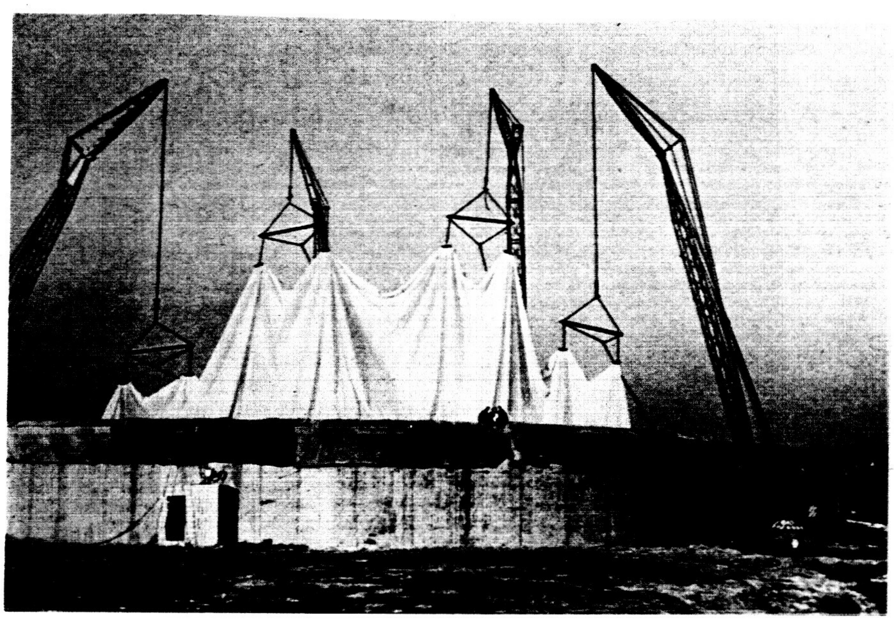

Fig.18 Mounting of the Radome

The rail was then aligned by means of a wedge device until the level difference between oil level and rail, determined by an optical method, was equal at all test points. Finally, the rail was permanently mounted to the foundation ring by means of a nonshrinking special casting compound. A check test showed that the deviations from the horizontal, in the final state, are only ±0.16 mm.

After completion of the antenna mounting, i.e., about nine months later, it was found that the foundation had settled by about 1.4 mm in the meantime but that there was no noticeable unilateral aftersettling.

f) Antenna Dome

To protect the antenna from inclement weather, specifically from icing and snow, it was decided to use an inflatable radome in Raisting (as in Andover and Pleumeur-Bodou). The dome of 48.8 m diameter was attached by 320 screws to the supporting wall, over an angle frame and suitable mounting clamps. The /293

material of the dome is 1.8 mm thick and consists of two Dacron fabric layers laminated at 45°C by means of Hypalon which is an ultraviolet-resistant synthetic rubber. For further protection, both sides of the fabric are given additional Hypalon coatings. At 6 Bc, the dielectric constant of the material is $\epsilon = 3$ and the loss factor $\tan \delta = 1.2 \times 10^{-2}$. At a dry outer skin, a noise contribution of 12°K is expected.

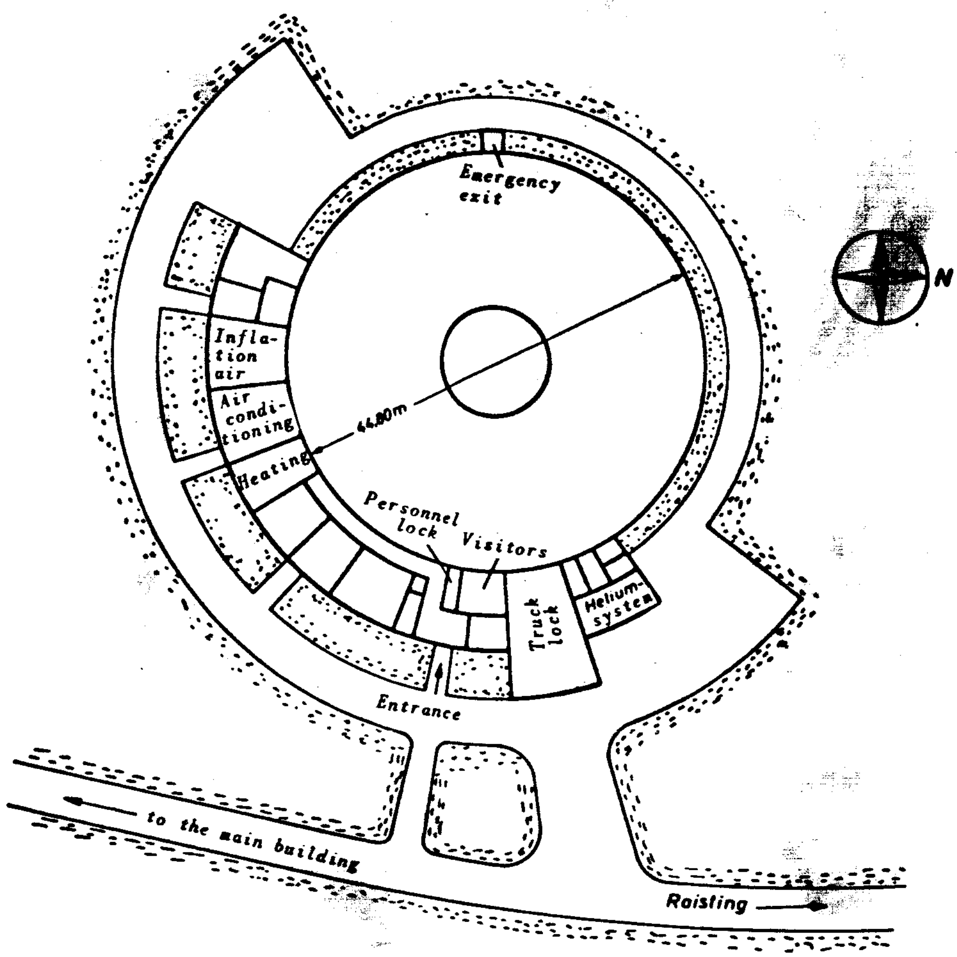

Fig.19 Ground Plan of the Antenna Building

For reasons of deadline, the same US material was used as for the antennas in Andover and Pleumeur-Bodou despite the fact that a thinner fabric with a lower noise factor could have been selected for the Raisting installation.

The cover, laminated together in long strips and weighing 13 tons, was /295 delivered in one large crate. The surface of the radome is 5200 m² and the volume 56,000 m³. The inside pressure is automatically controlled as a function of the wind velocity. The normal excess pressure is kept at 30 mm water column. At wind velocities above 70 km/hr, the pressure is increased to 70 mm w.c. At still higher wind velocities, provision is made for 140 mm w.c.

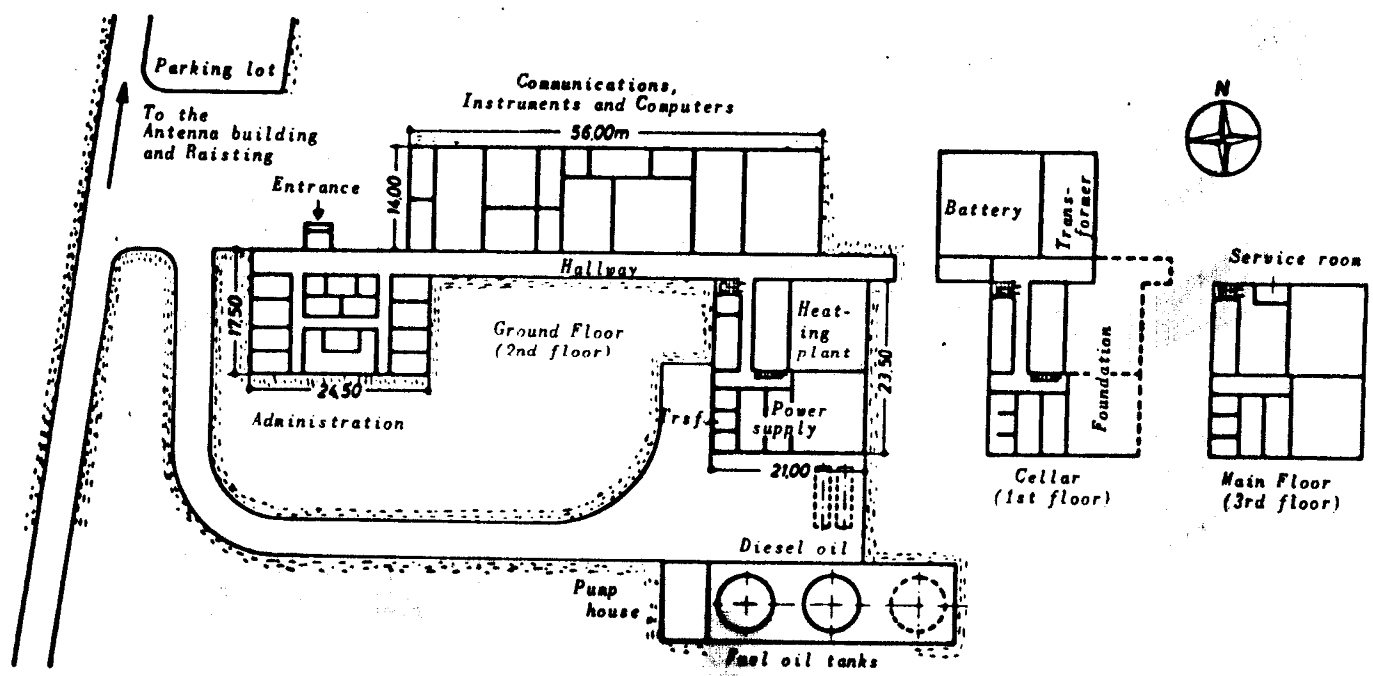

Fig.20 Ground Plan of the Main Building

The blowers required for producing the compressed air, take in fresh air over a dehumidifier from a stack erected at a distance of 50 m from the outside wall of the radome. For producing the compressed air, an inflation-air unit with five blowers is used. Two of these blowers operate in the first stage; additional blowers can be automatically cut in for increasing the pressure in accordance with the wind velocity. Figure 18 gives a general impression of the radome erection.

To prevent snow and ice from forming on the outside walls, an extensive heating system is required. So that the waste gases of the heating plant cannot produce harmful deposits on the radome skin, the heating plant had to be erected at a sufficient distance from the radome. Therefore, it became necessary to erect another building at a greater distance, in addition to the actual antenna structure which is built as a lean-to of the radome supporting wall and is kept to as small as possible a size to prevent interference of the proximity field which would impair the antenna characteristics; this additional building is scheduled as a central building for supplying future additional antenna systems with heat.

The ground plans of the two buildings are given in Figs.19 and 20, which also show the overall layout and a rough arrangement of the individual rooms. An outside view of the antenna building with the radome and, in the background, the main building is shown in Fig.21.

g) Lightning Protection

To prevent damage by lightning, the bearings for azimuth and elevation as well as the path between base frame and runway rails are bridged electrically conducting, by suitable means. Since the rails are well grounded, these measures are considered adequate at present. If lightning should strike the radome, only a small hole - probably as large as a dime - would be produced in the cover, as shown by various experiments. Flaming of the fabric is quite impossible since the slight air current, produced by such a hole in the radome, would prevent any flame formation.

h) Antenna Radiation Pattern, Results of Model Tests

To obtain sufficient data, in the shortest possible time, on the expected radiation characteristics of the antenna, several detailed model tests were made (Bibl.10). Measurements on a parabolic reflector of 3 m diameter, at /297
a frequency of 34.7 Bc (which, for the large antenna, corresponds to a frequency of 4.17 Bc) showed satisfactory results. The obtained radiation pattern for the H_{11}-wave type, used in communications, is shown in Fig.22. The asymmetry of the pattern apparently is due to some peculiarities in the experimental setup. In addition, it should be taken into consideration that the tolerances in a model are not within such strict limits as would correspond to the manufacturing accuracy of the large antenna. Therefore, the minor lobes /298
of the final antenna might differ slightly from the model tests. However, it is expected that the full-scale characteristics will actually be better rather

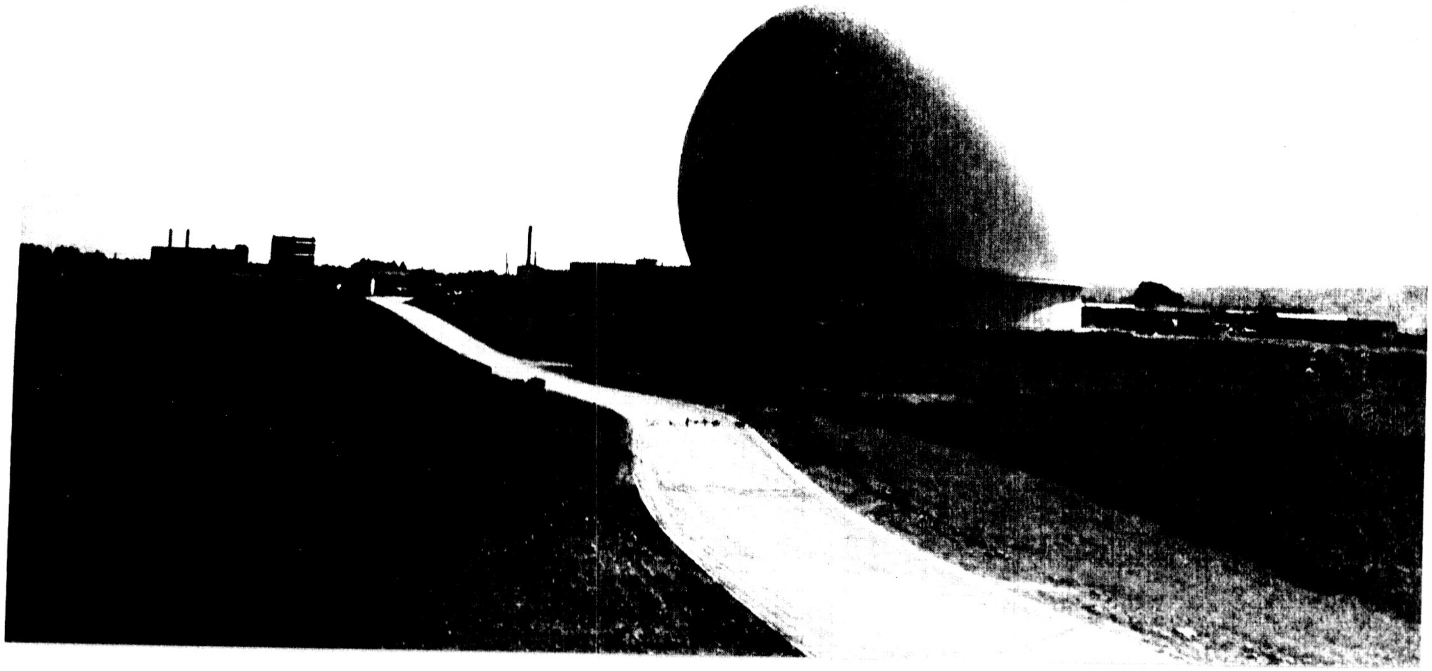

Fig.21 Antenna Building with Radome, Main Building in Background

than poorer, because of the high manufacturing accuracy. The half-wave width (3 db value) was determined on the model as being 0.245° (Fig.23). For the gain in the case of circular polarization, a value of 57.5 db was obtained. Accordingly, at 6.4 Bc a gain of about 61 db can be expected in the full-scale antenna.

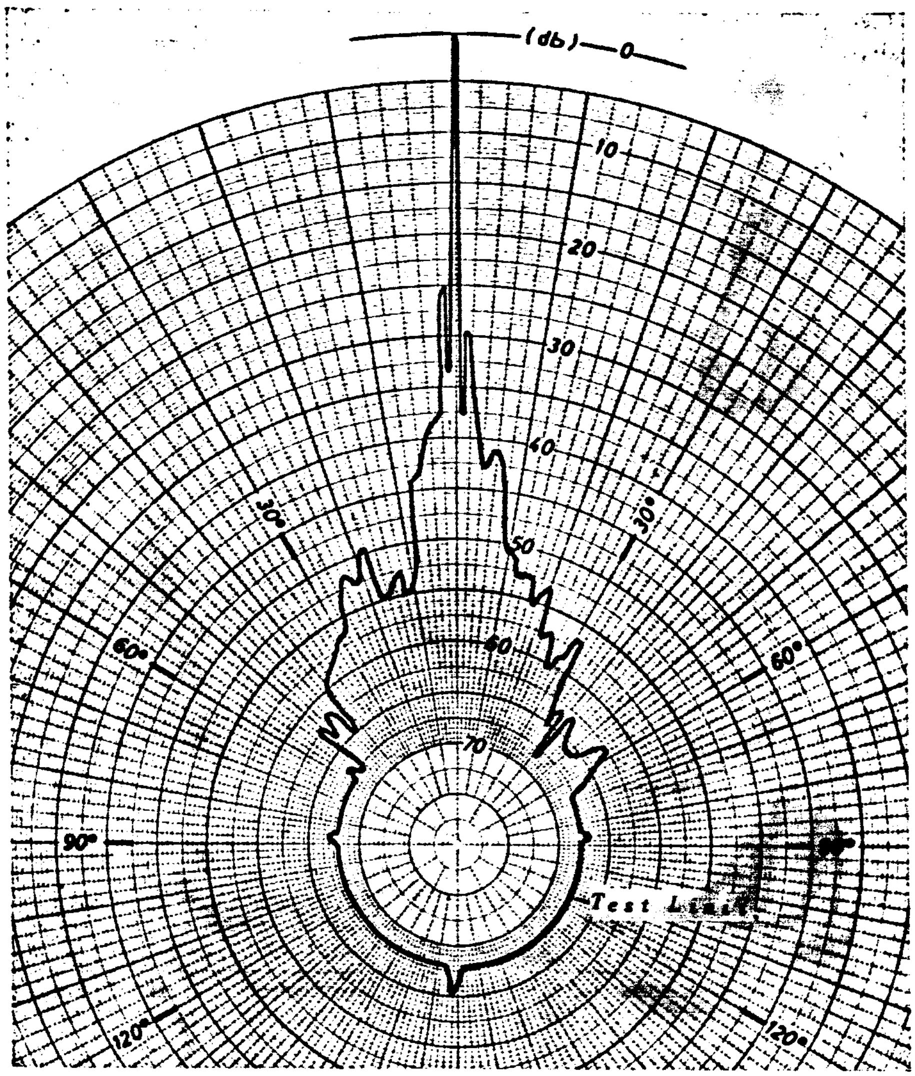

Fig.22 Antenna Radiation Pattern (H_{11}) Measured on a Model of 3 m Diameter

The E_{01}-wave type, which is significant for the automatic antenna tracking by means of the monopulse method, was also measured on the model (Fig.23). The two maxima spaced by 0.30° are only 5 - 6 db below the H_{11}-maximum. The distinct minimum in the direction of the main beam is by more than 20 db lower than the two maximum values. On the basis of the test conditions, it can be expected that the minimum of the full-scale antenna will be several decibels

lower, which should be of advantage for the antenna tracking.

The model tests also permitted very accurate investigations on the type of holder for the auxiliary reflector. Since high accelerations are occasionally expected in the rotary motion, any vibration of the holder must be prevented.

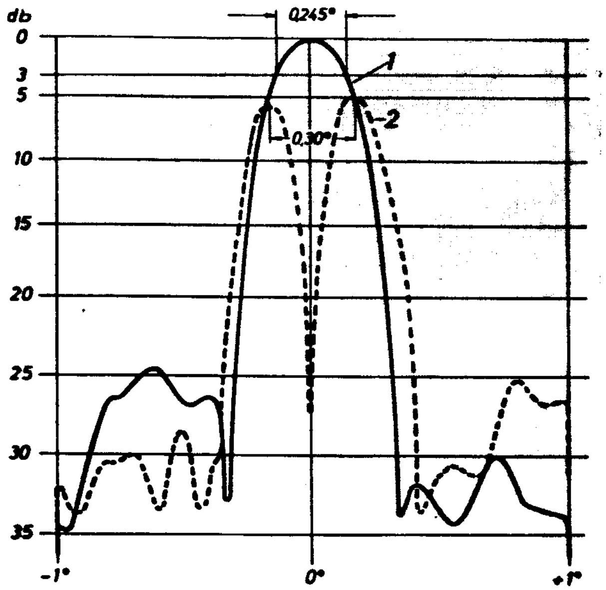

Fig.23 Antenna Radiation Pattern in Direction of the Main Beam, Measured on the Model of 3 m Diameter
1. Wave type H_{11}
2. Wave type E_{01}

For reasons of stability, it was decided to use four spacing posts. As material for these supports, dielectrics that show undesirable radiation and would contribute to an increase in noise temperature are quite unsuitable. Therefore, usually metal is the preferred material. In this case, proper shaping of the profiles is necessary so as to prevent - as far as possible - any diffraction along the edges. For this reason, lattice girder constructions are not recommended. We used steel supports with constant elliptic cross /299
section for the Raisting antenna.

The final radiation pattern of the Raisting antenna has not been defined. However, it is intended to run accurate tests on this point. For this purpose, a test oscillator will be required, to be erected at a distance $r \geq 2\ D^2/\lambda$ at which the far field of the antenna is sufficiently well developed. At 6390 Mc corresponding to a wavelength of $\lambda = 4.7$ cm and a diameter of $D = 25$ m, a minimum distance of about 25 km will be required. Such a test station is to be erected on the Vorderes Hörnle Mountain, at a distance of about 29 km from Raisting. In selecting the terrain profile, special attention was paid to have the propagation ratios along the test section coincide satisfactorily with the free-space propagation.

2. Communications Installation

Figure 24 gives a block diagram of the broadband installation.

The system has been laid out for telephone and television transmission. Since the satellites Telstar and Relay operate with only a single transponder, transmission in broadband telephone experiments is possible only in one direction. In two-way operation, such as in telephone operation with two radio-frequency carriers, staggered by 10 Mc, only 60 telephone channels at most can be realized. In Raisting, CF installations with 12 channel converters and fork connections are available for experimental purposes. By means of a FM 120/2000 directional radio line, connection with Munich has been established over the Zugspitze Mountain. Experiments or occasional demonstration calls, therefore, can be made not only from Raisting but from any town in West Germany. The same possibilities are available for experiments in telegraphy, telemetry, and facsimile transmission.

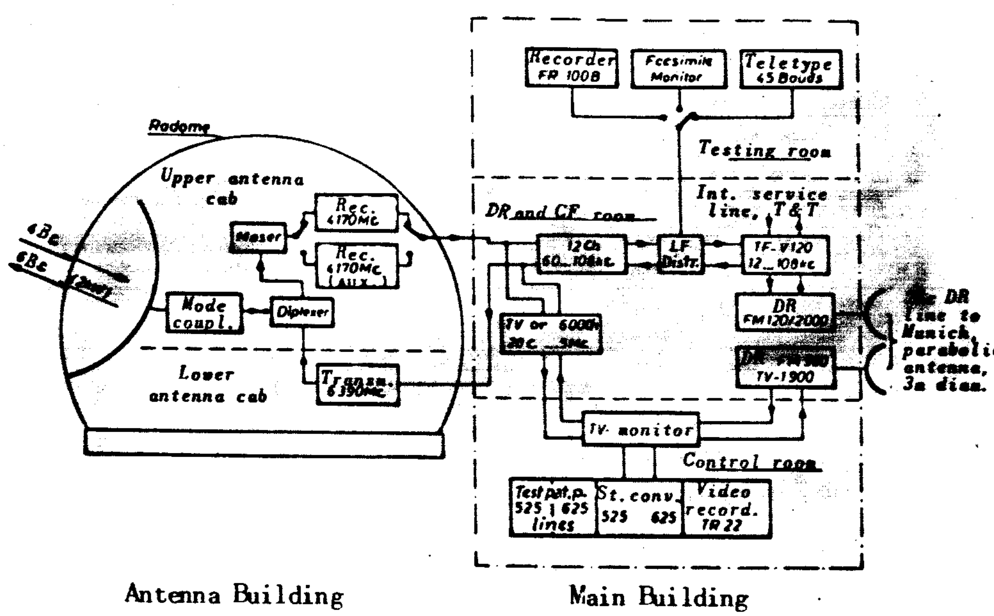

Fig.24 Block Diagram of the Broadband System

For television transmissions, a directional radio line is also available so that connections with various television studios in West Germany and in other countries can be established in both directions. Because of the differing television standards in the various countries, the ground station Raisting had to be equipped with a standards converter. Since several television standards are in use in Europe, no standards conversion is made in the US for transmissions to Europe so as to prevent a double conversion in programs beamed simultaneously to several European countries with differing standards. For this reason, an agreement has been reached that the standard will always be converted at the European end, since standards converters are required there anyway.

To be independent of the transmission times and to make any desired television transmission experiments, a television recorder and a test pattern pick-up were provided. Equipment for experiments in telegraphy, telemetry, and facsimile transmission is also available (Fig.24).

In the base band, three connections are scheduled for both transmitter /300
and receiver: one connection for AF transmission and two connections for television, i.e., separate ones for picture and sound. The picture, at simultaneous transmission of the synchronized sound, is limited to a bandwidth of 2.5 Mc while the sound carrier is near 4.5 Mc. In the transmitter and modulator, mainly building blocks of a newly developed 6-Bc directional radio system with 10 watt output power are used. Except for the traveling-wave tube in the output amplifier, all units in this system are transistorized.

The subsequent 2-kw output stage contains a water-cooled traveling-wave tube which is focused by a permanent magnet with periodic build-up. The deceleration of the propagation velocity of the electromagnetic wave, interacting with the electron stream, is obtained in this tube by a gang of magnetically coupled resonators. For changing the tubes, the magnet can be opened in longitudinal direction (Fig.25). The output power of the transmitter unit can be varied by a variable damping element inserted between test oscillator and power stage, so as to allow for differing distances from the satellite. This measure is necessary since the control range in the satellite receiver is limited for weight reasons and since, in consideration of the formation of intermodulation products during two-way communication over the one transponder in the satellite, it is necessary that the carriers incident on the satellite from the two separate ground stations are not too strong and have approximately the same /302
level. The power stage of Raisting is so designed that a second tube, with full accessories, as well as the operating tube itself can be kept under constant high vacuum by means of an ion getter pump so that it is easy to change from one tube to the other in the shortest possible time. In general, the transmitter is so laid out that it can be cut in automatically by remote control. The operating state of the entire system can be monitored constantly on a control panel.

The transmitter system, including the output stage, is erected in the lower antenna room. The damping of the lead-in from the transmitter output to the flange of the diplexer installed in the upper antenna room, is only 0.5 db because of the extensive use of round waveguides of 54 mm diameter.

The diplexer with the polarizer (Fig.26) has the function of separating the 6-Bc transmitting channel from the 4-Bc receiving channel and, in addition, of transforming the vertically polarized 6-Bc wave coming from the transmitter into a right-circular wave and the left-circular wave coming from the antenna into a horizontally polarized wave. Because of the great level difference between transmitter and receiver, the polarization bypass intended for the separation is not sufficient. Therefore, a low-pass filter is added at the receiving end, which discriminates against the 6-Bc transmitter frequency at the input of the 4-Bc receiver.

The beacon signal of 4080 Mc for the automatic antenna fine-tracking is

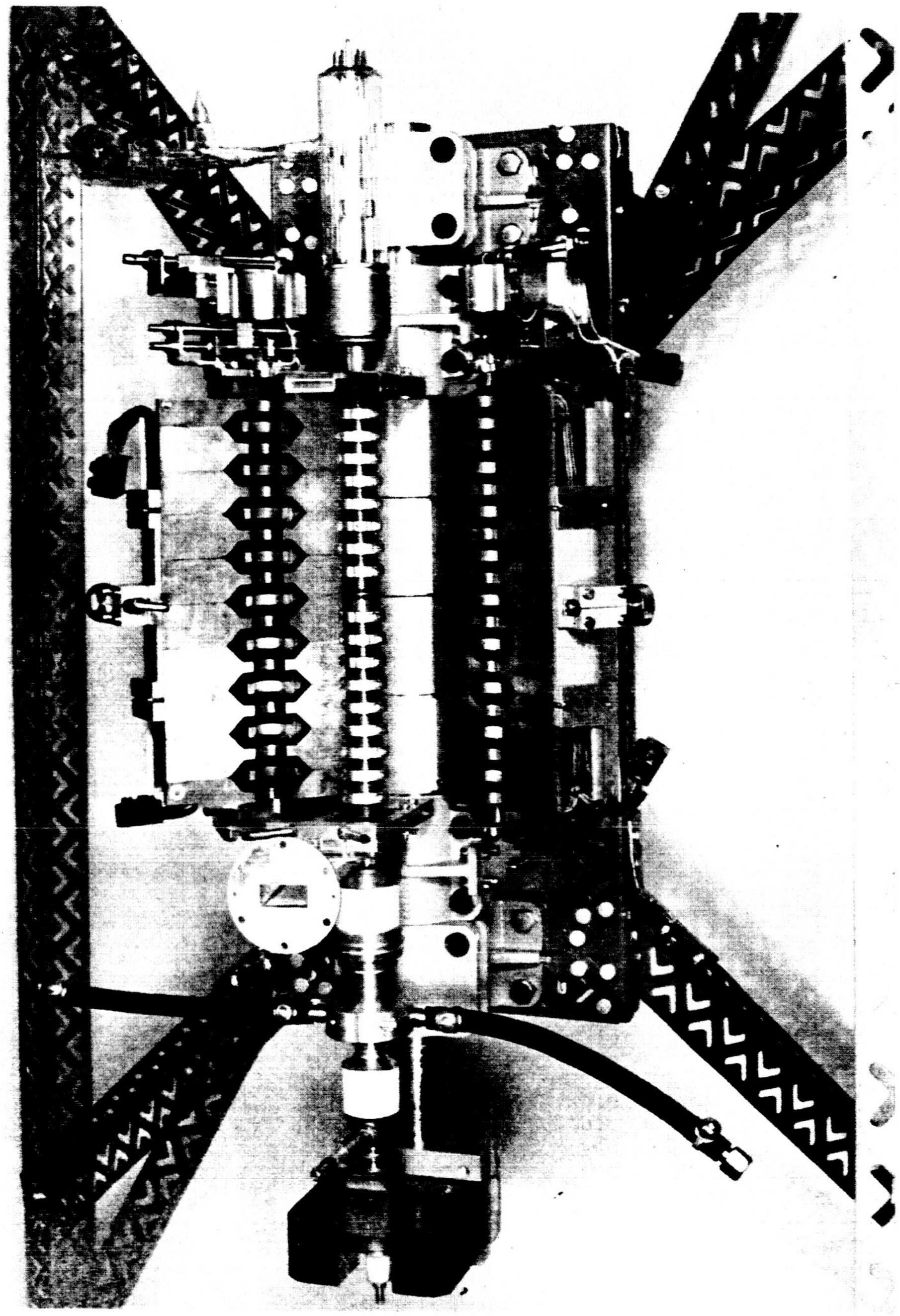

Fig.25 Output Stage (2 kw) with Open Covers

decoupled directly behind the antenna, in the mode coupler.

The traveling-wave maser, manufactured in the USA, whose HF portion including the ruby crystal is housed for cooling purposes in a four-chamber Dewar

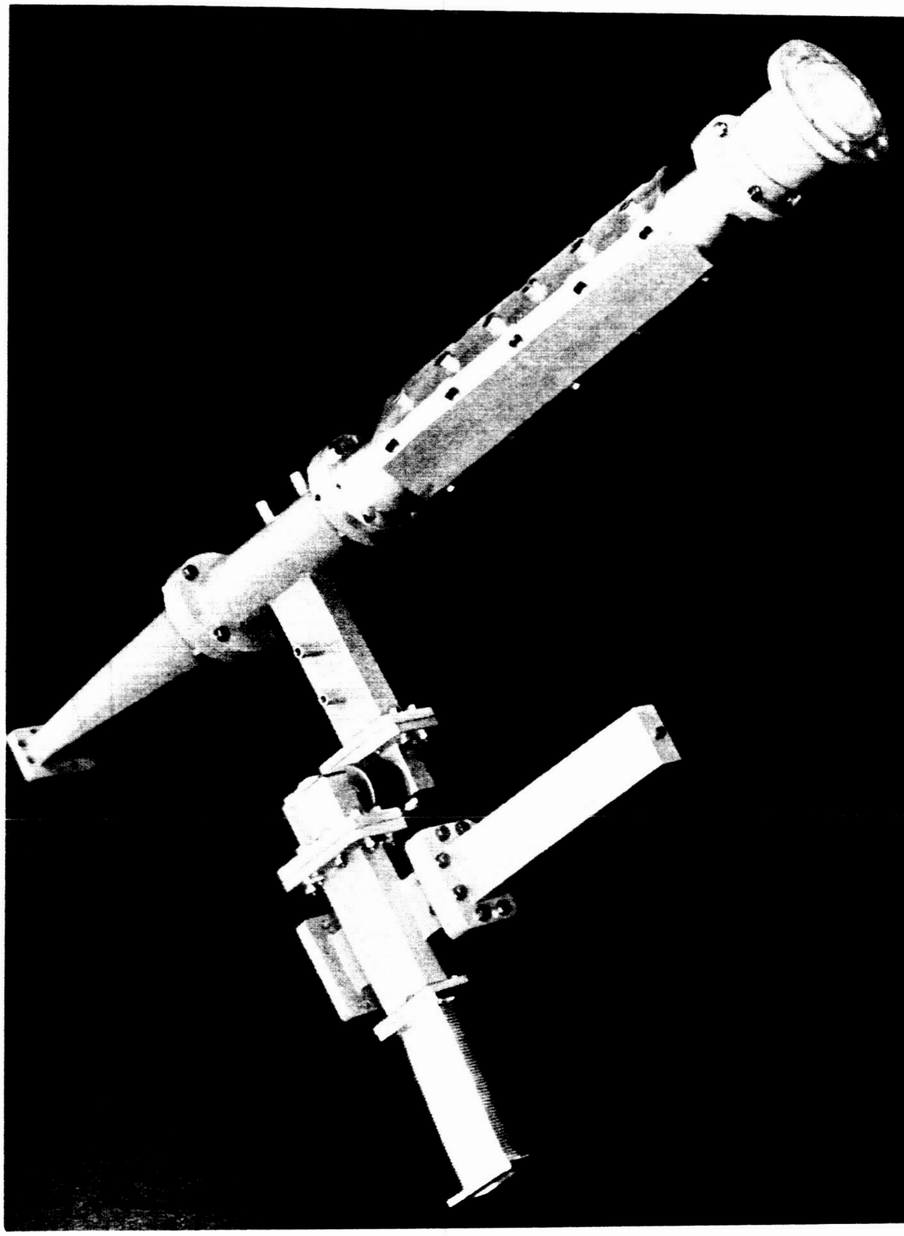

Fig.26 Diplexer of the Broadband System (Round Waveguide to the Antenna)

vessel, is the same type as that used in the Andover system (Bibl.5). The extremely low operating temperature of $4^{\circ}K$ is obtained by means of liquid helium. For precooling of the system to $77^{\circ}K$, liquid nitrogen is used.

The amplification of the maser, at 3.5° noise temperature, is about 40 to 42 db. The maser has a bandwidth of 16 Mc between the 3-db points. Since, a total passband region of 25 Mc maximum is desired, the restrictive transmission characteristics of the maser were compensated by adding a corresponding antidistortion element in the IF part, following the converter, thus extending the bandwidth of the entire receiving system to 25 Mc. In the demodulation stage, FM negative feedback (Bibl.5) is used for reducing the critical value.

To prevent dropout of the equipment, switch-over to a standby receiver at the output of the maser is provided (Fig.24). In addition, a second maser is installed in the upper operating room since, as shown by practical experience,

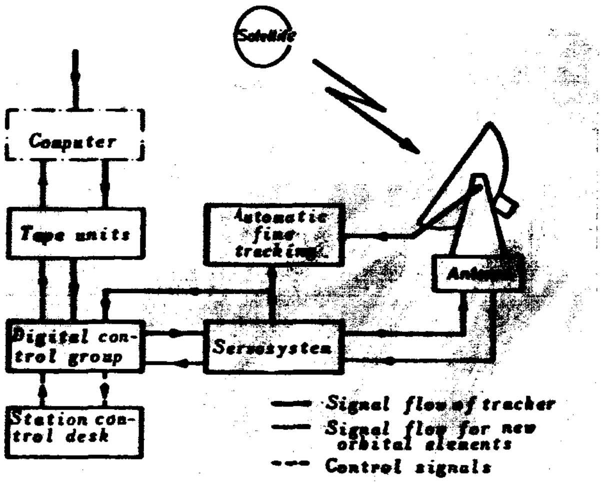

Fig.27 Flow Sheet of the Tracking System

an occasional dropout of the maser must be expected during cleaning or overhauling. Unfortunately, a simple change-over with HF switches is impossible in this case since the additional damping produced by such a switch would lead to a noticeable increase in noise.

A closed cooling circuit for the maser with liquid helium was scheduled /303
but is not yet available in a suitable form. Thus, the helium and nitrogen required for operation of the maser must be filled into the corresponding Dewar chambers which have a capacity of about 10 ltr. In 24 hours, the consumption of liquid helium is about 12 ltr and that of liquid nitrogen about 5 ltr, /304
so that one filling is sufficient for 20 and 50 hours, respectively. Because of the high cost of helium, the helium gas escaping from the maser in Raisting is conducted over a pipeline to a helium regenerating unit in the antenna building where it is stored in a gas holder or, over a compressor, is stored under pressure in a bank of five bottles. Before the gas is fed to the liquefaction unit itself, it must be purified. The regeneration of 12 ltr liquid helium takes about three hours. Otherwise, the storage of the helium gas is completely automatic so that the installation requires little attention or

servicing.

For transporting the liquid helium to the upper antenna room, special canisters of 25 ltr capacity are used, procured from the USA.

3. Antenna Tracking System

Because of the strong directivity, it is necessary to align the antenna beam accurately with the satellite. For this, extensive tracking equipment is required; for reasons of deadline, this equipment was procured from the USA and corresponds accurately to the system used in Andover. However, in difference from Andover, no commando tracker and no precision tracker (Bibl.5) were used in Raisting since there was no need for an initial determination of the orbital data. The basic structure of the tracking system in the Raisting unit is shown in Fig.27. As this general flow diagram indicates, program control and automatic fine tracking are scheduled. The orbital data stored on magnetic tape and determined in a computer on the basis of NASA data, are fed to the digital control group. This group interpolates the data, recorded at four-second spacings, in a 128-cycle rhythm and furnishes the corresponding control potential to the servosystem which operates on the analog principle. The accuracy of the calculated orbital data generally permits a tracking of the satellite orbit with an angular accuracy of about 0.01°.

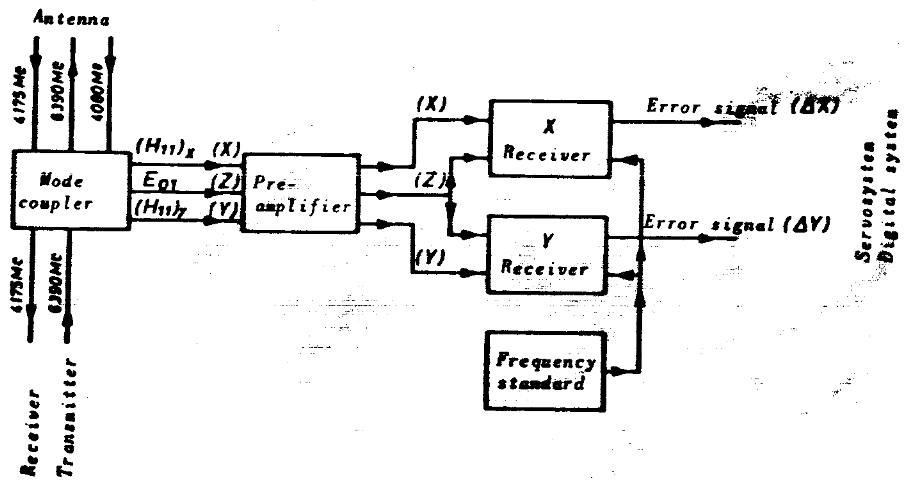

Fig.28 Block Diagram of the Automatic Fine Tracking

The automatic fine tracking permits a more accurate alignment with the /305
satellite. As soon as the satellite is operative, it will emit a beacon signal of 4080 Mc in addition to the regular communications signal. If the satellite coincides with the electric axis of the antenna, an H_{11}-wave will be excited in the antenna waveguide. In the case of deviation, wave types of a higher order will be produced. The diameter of the antenna waveguide is so selected

that, in addition of the H_{11}-wave, only the E_{01}-wave is able to propagate (see Fig.23). By using the H_{11}-wave as reference signal and the E_{01}-wave as error signal, the position of the satellite can be fixed accurately in each individual case. To obtain an error signal in the azimuth, the x-component of the H_{11}-wave is compared with the E_{01}-wave. Possible deviations in elevation are detected by comparing the E_{01}-wave with the y-component of the H_{11}-wave. A block diagram of the automatic fine tracking is shown in Fig.28. The signals $(H_{11})_x$, $(H_{11})_y$, and E_{01} produced in the antenna waveguide are decoupled by means of the mode coupler and are supplied separately to the preamplifier of the fine tracking, where they are first reduced, after parametric HF amplification, to the intermediate frequency of 60 Mc and then further amplified. These signals are then fed to the x- and y-receivers. At the two receiver outputs, after comparison with a frequency standard, the direct-current error signals Δx and Δy are obtained, corresponding to a deviation in azimuth and elevation.

The error signals can be supplied either directly to the servosystem and thus used for controlling the antenna or else are heterodyned with the digital error signal of the digital control group which then modulates the servosystem. The scan of the automatic fine tracking is given by the width of the main lobe of the antenna radiation pattern at 4080 Mc and is about 0.2°. In satellite tracking by means of automatic fine tracking, the satellite itself forms a part of the control loop, representing the guide factor of the control circuit. The automatic fine tracking permits a setting accuracy of about 0.003°.

The actual antenna position is read from accurately machined data gear /306
rims, which are mounted next to the central bearing and next to the large elevation bearing. The data gear rims, across data gears, engage so-called rotary data pickoffs which furnish a signal proportional to the antenna position and thus close the control circuit of the servosystem. These rotary pickoffs are excited with 420-cycle and 1090-cycle alternating voltage, respectively.

Figure 27 also shows the signal flux of the data to be recorded during one satellite tracking. From the antenna, the data reach the digital control group over the servosystem; this control group feeds the data to a tape unit for recording. Such data recordings can then be used as a basis for calculating new control tapes.

For checking the automatic antenna tracking (autotrack) even without satellites, a sighting tower with satellite simulators for Telstar and Relay must be erected at a distance of $r_1 \geq D^2/2\lambda$, at which the E_{01}-wave required for control can fully develop in the receiver system of the ground station. For the pilot frequency of 4080 Mc, corresponding to a wavelength of $\lambda = 7.35$ cm and an antenna diameter of D = 25 m, a minimum distance of 4250 m was calculated. For this tower, we selected the "Hartschimmelhof", a farm at a distance of 6000 m where we erected a 50 m high steel tower for mounting the sighting antennas. The simulators, in addition to the beacon transmitter, also contain transponders of the same type as those carried by the satellites themselves, so that the transmission status of the entire system can be checked at any time over the sighting tower. In this check test, the input and output level of the ground station correspond to the transmission conditions over the true satellite.

VI. POWER SUPPLY, HEATING AND VENTILATING SYSTEMS

Figure 29 gives a greatly simplified sketch of the power supply for the broadband system. The ground station is connected to the high-tension line over a 3.6 km long cable with the overland 25-kv line of the Isar-Amperwerke, passing close to Raisting. The three-floor heating and machinery portion of the main building contains two transformers with a capacity of 800 kva each, one of which is used only as a standby unit.

In order to be independent of mains voltage fluctuations and mains failure, the power supply unit was equipped with batteries, auxiliary power plants, and rotary transformers. During power failure of up to one hour duration, communications can be continued without interruption. Failures of longer duration are quite unlikely. Nevertheless, measures have been taken for supplementing the power plant by a second auxiliary unit before starting commercial operation.

The two batteries with a capacity of 2304 amp-hr each, at 10-hour discharge, are buffered over three parallel-working silicon rectifiers. The three equal-type transformers are used for the technical units that require uninterrupted supply; the transformers Nos.1 and 2 with 60-cycle alternating voltage /307
are intended for the units purchased in the USA. The transformer No.3, after a simple manual switch-over, is able to furnish either 50 or 60 cycles so as to substitute temporarily for either the transformer No.1 or No.2 whenever necessary, such as in cases of dropout. The consumers, grouped with the transformer No.3, must be fed from an auxiliary power source during this time. At 50 cycle, the power of the transformer is about 20% lower than at 60 cycles.

The two air-cooled Diesel engines for the auxiliary power plants which, on mains failure, will cut in automatically after a certain time delay, have a power of 155 kva each. The 50-cycle consumers which, in the case of power failure, are directly supplied by the auxiliary power units (APU) are subdivided into two groups. By an automatically operating switch-over unit, supply to the most important consumers is continued whenever an auxiliary power unit fails, so that communications will not be interrupted.

An especially high operating reliability is required of the blowers for the radome inflation-air unit. For this reason, in the case of power failure these blowers are supplied by a quick-starting special auxiliary power unit of 23 kva, erected in the antenna igloo. As soon as the two large auxiliary power units in the central building are able to take over or as soon as the mains voltage has been reestablished, the small auxiliary power units cut out automatically. An additional safety device for the inflation-air unit is given /308
by the fact that, after manual switch-over, the blowers can also be operated from the battery over the transformer No.3. Finally, provision has been made for connecting the blowers to a mobile auxiliary power unit, if necessary.

The narrow-band system is supplied over a voltage regulator by the local 8-kv mains, to which also the town of Raisting is connected, using a special transformer which has been temporarily erected in the immediate vicinity of the station. No provision has been made here for ensuring continued operation in the case of power failure. Consequently, occasional dropouts must be expected.

Only in the case of prolonged failure of the overland network, provision has been made for maintaining operation by means of a mobile auxiliary power unit.

For heating the main building, the antenna igloo, and the radome, two boilers with a capacity of 3.5 kcal/hr each have been installed. The system

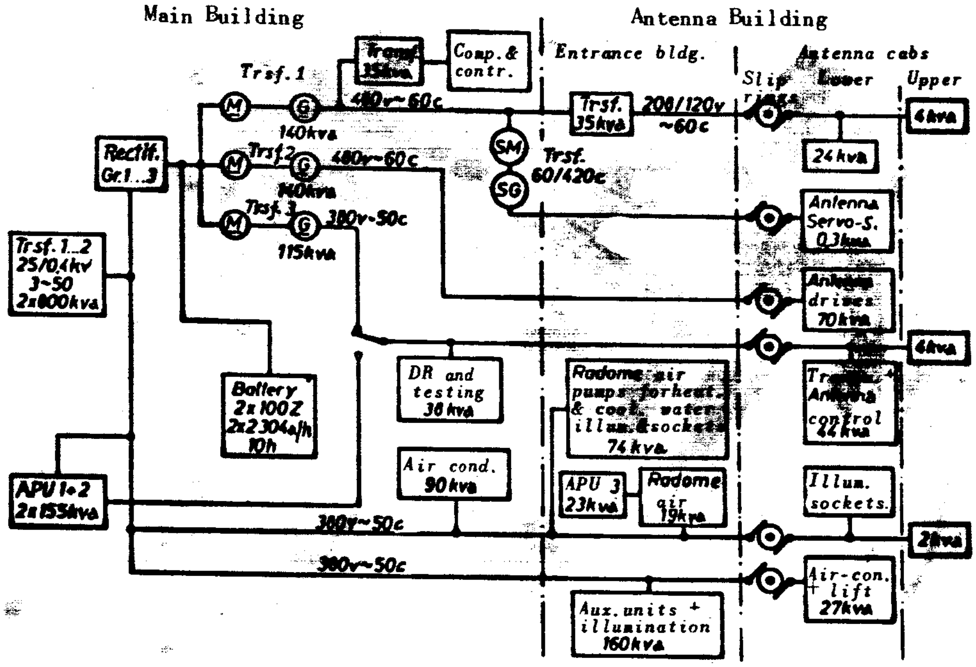

Fig.29 Block Diagram of the Power Supply for the Broadband System

operates on the hot-water principle with an overhead expansion tank and own steam vent as well as nitrogen cushion for the startup operation. The boilers have such dimensions that the heat supply can be fully maintained on failure of one of the boilers. Both boilers are equipped with continuously variable oil burners (pressure atomizers), each having an oil gage and a counter of operating hours. Each boiler is provided with its own control desk which also houses the measuring instruments for flue-gas temperature and CO_2 content. The control desks are erected in a service room directly next to the boiler system.

The combustion air is fed to the boilers over individual blowers installed in the outer wall of the boiler house. As fuel, extra light fuel oil is used, stored in two vertical fuel tanks outside of the building, having a capacity of 300,000 ltr each. For preventing wax formation, both tanks and the oil lines are preheated with hot water and, in combination, also with an electric heater.

For starting the unit, a rotary pump is used, which heats the recycle

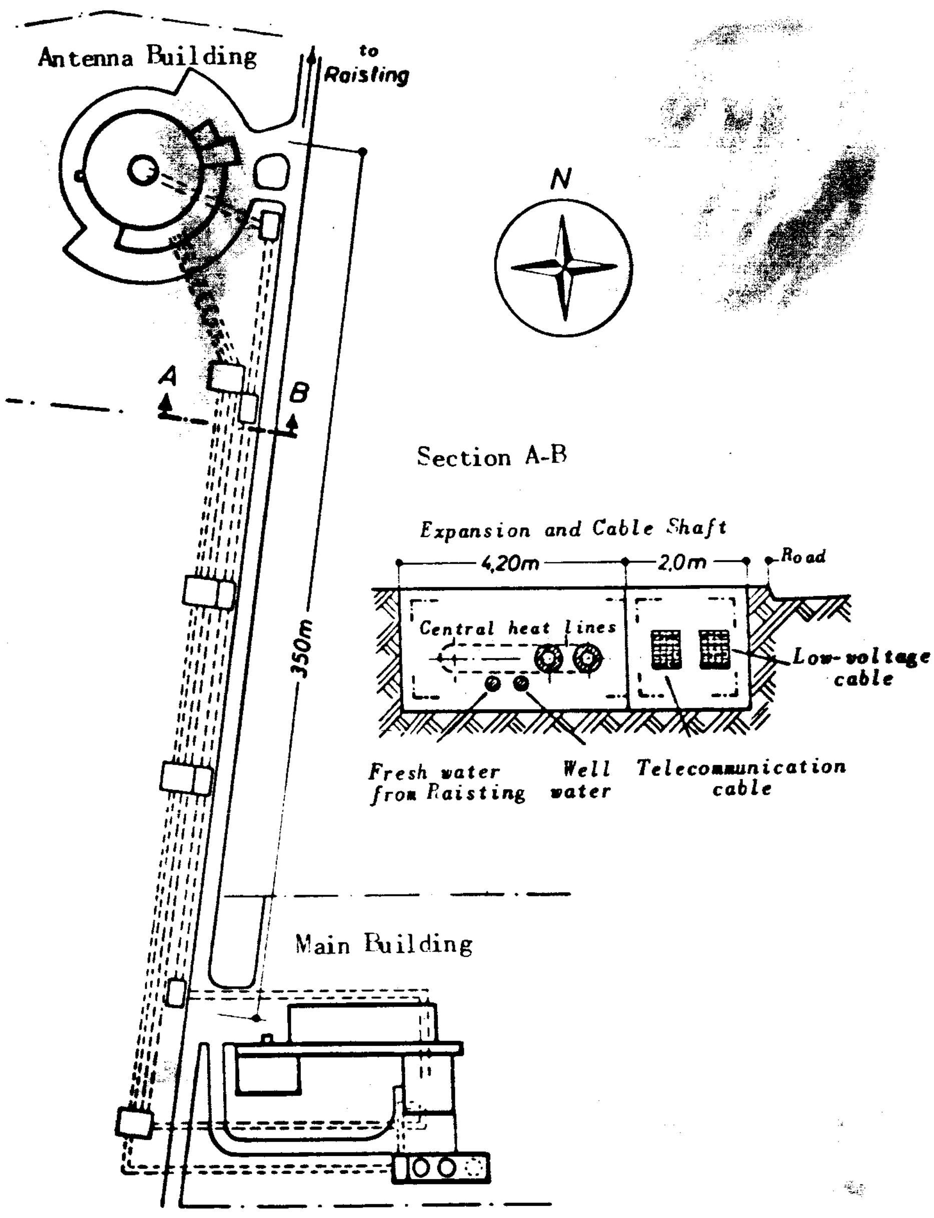

Fig.30 Position Plan of the Broadband System

water for the boiler by admixture of feed water.

The hot water of a maximum temperature of 160°C and a pressure of 13 atm (gage) is supplied to the countercurrent units in the individual buildings by three rotary pumps over a main distributor. Here, the hot water in the countercurrent units is transformed into warm water of a maximum of 105°C feed-water temperature and 70°C recycle-water temperature.

To have the large antenna reflector retain its contour accuracy, excessive temperature fluctuations and temperature differences within the radome must be avoided. For this purpose, eight air circulators are distributed uniformly over the inside of the radome along the supporting wall, providing constant agitation of the air. These circulators take in air and discharge it along the radome wall far toward the top so as to prevent heat stagnation in the upper portion of the radome. In winter, the air is conducted over the warm-air registers of the hot-water heating system, so as to maintain a temperature of +20°C within the radome, even at outside temperatures down to -24°C.

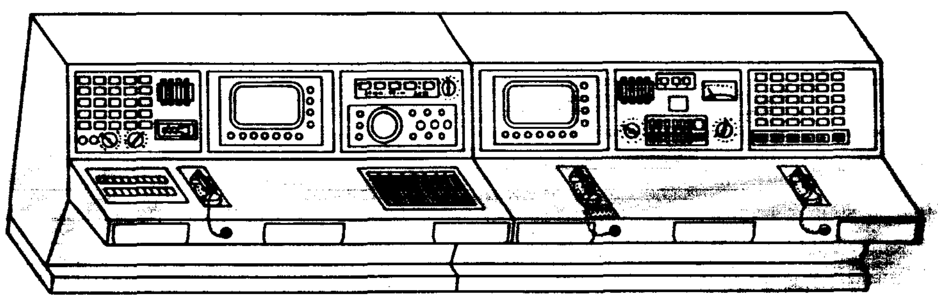

Fig.31 Monitoring and Television Control Console

The two antenna operating cabs are air-conditioned. The required cool- /310
ing water is supplied and recycled over the rotary coupling. The air-conditioning unit itself is erected in the antenna igloo. The cooling water is simultaneously used for dissipating the heat from the closed-cycle cooling system of the 2-kw power tube, which operates with distilled water.

In the main building, the rooms for the computer, the control room, and the testing room are fully air-conditioned within the limits from 22° to 26°. The directional radio room and the instrument room only have simple aeration and ventilation.

The cables between main building and antenna igloo, as shown in the position plan of Fig.30, run along the connecting road. Since the terrain on both sides of this road is used as farmland, an open or plate-covered cable trench was not in question. For telemetering and low-voltage cables, cable conduits were used. Along these conduits were also laid the steam pipes for the heating system and two water lines, one for water from the town of Raisting and one for water piped from the deep-well system on the grounds of the main building.

VII. MONITORING AND TELEVISION CONTROL DESK

Since the technical equipment of the ground station is housed in various buildings and distributed over a large number of different rooms, a monitoring and television control center (Fig.31) was erected in the control room of the main building. The multiple signal fields and the various monitors enable the senior engineer to monitor constantly the operational status of the entire installation. All reports on operation are channeled into this center, making it possible to direct the entire installation from this central point and, in the case of dropouts or failure, to take all necessary measures for maintaining /311 the operation. From the television control desk with its various switching possibilities for picture and sound, all switch-overs can be made as required for television transmissions in the ground station, equipped with test-pattern pickup, picture plotters, scopes, and standards converter.

VIII. FUTURE ASPECTS

Successful launching of the Telstar and Relay comsats has started a new era for worldwide communications. For the year 1965, experiments with a synchro satellite are expected, permitting 240 telephone channels between Europe and America. For 1966 - 67, a first global satellite system is planned which will create up to 1200 new intercontinental communications channels in various portions of the world. Systems that already allow multichannel communications, namely, relays between arbitrarily many ground stations, no doubt will open completely new perspectives in the very near future, using a technique which is being intensively studied in the various laboratories of the world.

The installations in Raisting, matched in their technical aspects to the Telstar and Relay satellites, presumably will be sufficiently flexible to work also with other satellites of the future, after minor modifications. There is no doubt that, to meet the demands of the start-up of commercial operation, a second large antenna system will have to be installed in the very near future.

IX. SUMMARY

In the ground station Raisting, the German Federal Post Office Department has erected a narrow-band and a broadband system for collecting practical experience in the field of communications over artificial earth satellites. In this pamphlet, the technical equipment of both systems in their basic design is described. Special emphasis is placed on details of the 25-m Cassegrain antenna with parabolic horn feed, since a design of this type has never been used anywhere else. The narrow-band system was taken into operation in fall of 1963 and the broadband system, in fall of 1964.

X. BIBLIOGRAPHY

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